PROCEEDINGS
THE INSTITUTION OF CIVIL ENGINEERS

PART II
OCTOBER 1956

MARITIME AND WATERWAYS DIVISION MEETING

20 March, 1956

Sir Arthur Whitaker, Vice-President, Chairman of the Divisional Board, in the Chair

The following four Papers were presented for discussion and, on the motion of the Chairman, the thanks of the Division were accorded to the Authors.

Maritime Paper No. 32

DESIGN OF SHIPS FROM THE CARGO HANDLING POINT OF VIEW

by

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SYNOPSIS

The subject is dealt with generally, and primarily from the point of view of the ship designer.

A conventional type of cargo liner is used as a basis to discuss certain fundamental design features and to point out where these are controlled by regulations or necessity. The possible effect on the cargo arrangements of incorporating in the design accommodation for a large number of passengers is indicated.

The usual method of handling general cargo is described and it is explained that the process of moving cargo from the quayside to its stowage position in the vessel is not the only problem to be considered.

It is noted that considerable loss of cargo space is occasioned when it is necessary to provide insulated chambers and also that the maximum utilization of cargo space depends on the design of the ship, the type of cargo, and the stowing of that cargo.

It is suggested that under present circumstances speeds for loading and discharge may be influenced more by the port facilities than by the design of the ship; also, that whereas the layout and equipment for a general cargo liner may not materially alter, new trades, or the stabilization of bulk trades, may call for new ports arranged for automatic handling and new ships would then be designed accordingly.

General principles

The ship designer knows the type of ship which has been evolved to carry the cargo of a particular trade and the port facilities which have been developed to suit the demand of that and other trades.

Before considering any radical alterations, the reasons for the existing design of the ship should be examined and if these appear to be valid, then each feature and handling operation should be reviewed for possible improvement.

Alteration to existing ports

It is assumed that the port authority will not alter existing equipment, etc., or provide specialized facilities unless it is clearly evident that the improvements would be to the ultimate benefit of the port and that the necessary funds are available. Accordingly, although a progressive policy of dock and port improvement may exist, the ship designer has to bear in mind that, where a port handles numerous trades for various shipowners, the facilities will not necessarily be altered to suit a specialized type of ship or trade.

Ship and service

As a basic ship, consider the single-screw 15-knot cargo liner which was designed and built as a standard ship under the auspices of the Ministry of War Transport during the latter stages of the 1939–45 war. The layout of the cargo spaces and cargo-handling gear is shown in Fig. 1 (Plates 1 and 2). The vessel was designed to carry general cargo (with particular emphasis on warlike heavy and/or bulky equipment); the ports or condition of the ports between which the vessel would operate, could not be forecast.

Design of ship

It is necessary to take account of the undermentioned features when considering the cargo arrangements for any ship which is to be employed on long international voyages.

Passengers

Large numbers of passengers and the requisite crew may be accommodated in superstructure decks amidships and over the cargo spaces without materially interfering with the layout of such spaces or prejudicing the derrick arrangement, but long hatch trunks through such accommodation tend to slow up the cargo-lifting process and are uneconomical in the use of space within the ship and some compromise has to be made in the size of the hatch.

Transverse watertight bulkheads

To meet the requirements of the principal classification societies, the ship must be divided longitudinally by the following transverse watertight bulkheads:

(*a*) collision bulkhead, forward;
(*b*) aft peak bulkhead to isolate the stern tubes;
(*c*) at each end of the machinery space; and,
(*d*) additional intermediate bulkheads in number related to length (three are usually required for a 400-ft ship, and five for a 600-ft ship).

For a cargo ship there is some latitude in the spacing of these bulkheads, but for a Class 1 passenger ship international regulations require the number and spacing of such bulkheads to be arranged to provide a hypothetical degree of safety in the event of flooding consequent on underwater damage. Assuming one hatch per compartment, the above factor decides the minimum number of hatches and controls the length of the cargo spaces.

Draught

The deepest draught may be controlled by a requirement to be able to sail at all states of the tide and the depth of water in the port and approach channel.

The lightest draught will be influenced by the deadweight to be carried.

Decks

The minimum moulded depth and position of the freeboard deck is related to the draught, since the freeboard is dictated by international regulations.

The vertical spacing and number of other cargo decks is arbitrary and these are arranged to suit the particular trade, observing that in deep holds lightly packed items might be crushed by the weight of those above and high 'tween-decks may present difficulties in manually loading and discharging.

Tramp ships and those principally employed in carrying coal or grain or similar commodities in bulk are usually fitted with two decks to form a 'tween-deck cargo space above each hold space proper, whilst cargo liners are usually fitted with three or more decks as in the vessel shown in Fig. 1.

Pillars

It is the normal requirement that the strength of the decks shall be such as to support cargo stowing at 50 cu. ft/ton over the full area of the deck and for the full 'tween-deck height; for an 8-ft 6-in. 'tween-deck height, this means a uniform loading of about 3·4 cwt/sq. ft of deck area. The designer has the choice of supporting this load by numerous pillars carrying shallow fore and aft members (girders) and shallow transverse members (beams), or by reducing the pillars and increasing the depth of the girders and/or beams and accepting some loss of effective stowage space beneath the deckhead.

For the vessel shown in Fig. 1 the loads are carried principally on deep, hatch-side-extended girders supported by a single pillar port and starboard at about mid-span. A more usual arrangement is to fit a pillar at each corner of the hatch.

Hatches and covers

Provided the International Load Line Regulations regarding integrity and strength are met, the designer is free to select the size, position, and the arrangement of hatch openings.

Generally, the larger and the more centrally situated the hatch, the easier it will be to load and discharge the space served. As in Fig. 1, one extra large hatch is frequently arranged to allow for the carriage of rolling stock, etc. The hatches to deep tanks present a difficulty since tightness must be obtained when carrying liquid cargoes and yet they must be sufficiently large to pass general cargo on other occasions.

Normally, portable or sliding beams in association with readily man-handled wood covers are fitted and, for refrigerated spaces, the beams are insulated and the covers take the form of wooden insulated plugs. Such arrangements are gradually being superseded, both for general and refrigerated cargo-space hatches, by steel or

aluminium sliding, hinging, or folding covers incorporating the supporting beam structure.

Masts, derricks, and winches

For a liner trading regularly between ports where there is adequate shore cranage or elevator gear and where no overside discharge into lighters is called for, the expensive outfit shown in Fig. 1 may be largely superfluous and tends to interfere with the working of the cargo by shore gear. Two mast-head (or equivalent) navigation lights must be carried; the aesthetic appearance of the ship's profile may be important and there is the possibility that the trade may alter and the ship be required to call where the port cranes are inadequate; also, some mechanical aid may be required for "breaking-out" cargo during unloading.

Deck cargo

In a ship carrying a large number of passengers most of the weather decks are required for recreation or equipment, but in the type of ship under review deck cargo may be carried fore and aft abreast and on the hatches; this requirement has influenced the width of the hatches and the siting of the winches.

Stability, trim, and strength

For general cargo carriers it is common practice to consider these items on the assumption that all the cargo spaces are filled with a homogeneous cargo of uniform density and some regard has to be paid to the longitudinal and vertical stowing of heterogeneous cargo.

Main propelling machinery and bunker arrangements

There are no regulations restricting the positioning of these items but, because of the large weights involved and the consumption of the fuel during the voyage, it is convenient to site them so that they do not adversely affect the trim of the vessel.

For the ship illustrated, the motor room is slightly aft of amidships with bunker and deep tanks immediately forward of it, but it is not unusual to reverse the relative positions of these. In twin-screw ships with numerous 'tween-decks, it is difficult handling cargo in the pockets formed outboard of the shafts and these are frequently plated over at the level of the tunnel to provide tankage or refrigerating machinery rooms, etc.

Other constructional details

Fig. 1 indicates diagrammatically the shape of some of the 'tween-deck cargo spaces. In addition to the pillars, girders, and beams already mentioned, the whole of the structural framework has to be well stiffened and bracketed to withstand the external forces of wind and weather at sea; access to the cargo spaces, tanks, etc., drainage and ventilation and fire-fighting arrangements all tend to interfere with the stowage or handling arrangements of the cargo and/or to reduce the effective carrying space.

Cargo handling

The precise practice varies from port to port and the commodity being handled. It is outside the province of this Paper to discuss the shore aspect but it may be convenient, when considering cargo handling on board, to review the usual procedure for handling general cargo.

Outward cargo is unloaded from road and rail transport, recorded, and laid out in the receiving shed in the port order in which it is to be shipped. It is then measured and port marked and is available for Customs' examination where required. Average mixed cargo is placed in "net-boards" on low platforms (skids) ready for moving by low-lift electric trucks to the appropriate hatch position alongside the vessel. Heavier or bulkier cargo is dealt with in a similar manner except that wire or rope slings are used in place of boards.

The percentage of the whole cargo which can be dealt with as above in the receiving shed so that loading may start as soon as the vessel comes alongside the loading berth, and continue without interruption, will depend on the size of the shed and the shore organization. If a vessel is to be fully loaded at one berth it may be necessary to fill and empty the receiving shed several times.

The lifts are handled from the quayside to the square of the hatch by the normal type of shore luffing cranes of capacity varying from 2 to 6 tons, or by the ship's derrick gear usually working on some "burtoning" arrangement for lifting and swinging. The average lift is about 2 tons, and the items are tallied on board.

According to conditions, one or more gangs of stevedores per hatch may be employed on board. A variety of improvised and seemingly primitive manual means are used by them to transfer the components from the hatch square to their allotted stowage space and the net-board or sling is returned for recharging. Shore labour is adjusted as necessary to suit the number of gangs employed on board.

Dunnage for the separation, protection, and ventilation of the different parcels of cargo is worked in by the stevedores as loading progresses and certain items, because of their weight or nature, may require special shoring, lashing, chocking, or positioning. Certain classes of cargo, i.e., explosives, corrosives, inflammable, or poisonous, require special stowage and may not be permitted in a passenger ship.

Finally, the stevedores ship the hatch beams and covers and the ship's crew secure the tarpaulins and locking bars.

During the loading process the Shipowner's Cargo Superintendent is kept advised regarding non or late arrivals of consignments and the scheme of loading is adjusted accordingly.

The discharging operation is generally similar but in reverse order to that described for loading. Portable lengths of gravity rollers may be used to assist in the transference of cased goods within the cargo space to the hatch square.

With general miscellaneous cargo it is impracticable to completely fill all the available volume within any cargo space; the lost space will depend on the design of the ship, the type of cargo, and whether the cargo is well stowed or otherwise. For example, in a vessel having insulated chambers designed for the most efficient stowage of fruit or meat homewards, about half the available space therein may be lost if motor vehicles are loaded outward.

Neglecting the space occupied by the refrigerating machinery, about 17–20% of the available space is taken up by insulation, air cooling batteries, and cooled air distributing trunks, which are sited within the boundary structure of insulated compartments.

General observations

The problem of cargo handling is not simply one of design of ship and/or port.

Experience at certain ports and loading berths has shown that general cargo and bulk cargo can be loaded and discharged into and from the conventional type of ship at speeds which are principally governed by the port facilities and organization,

and the land transport system. Assuming that these factors cannot be materiall improved, the most fruitful line of research might be to investigate possible ways reducing handling charges.

It is only rational to mechanize if the machines (with their attendant overhea expenses) can do the work more cheaply than by manual labour.

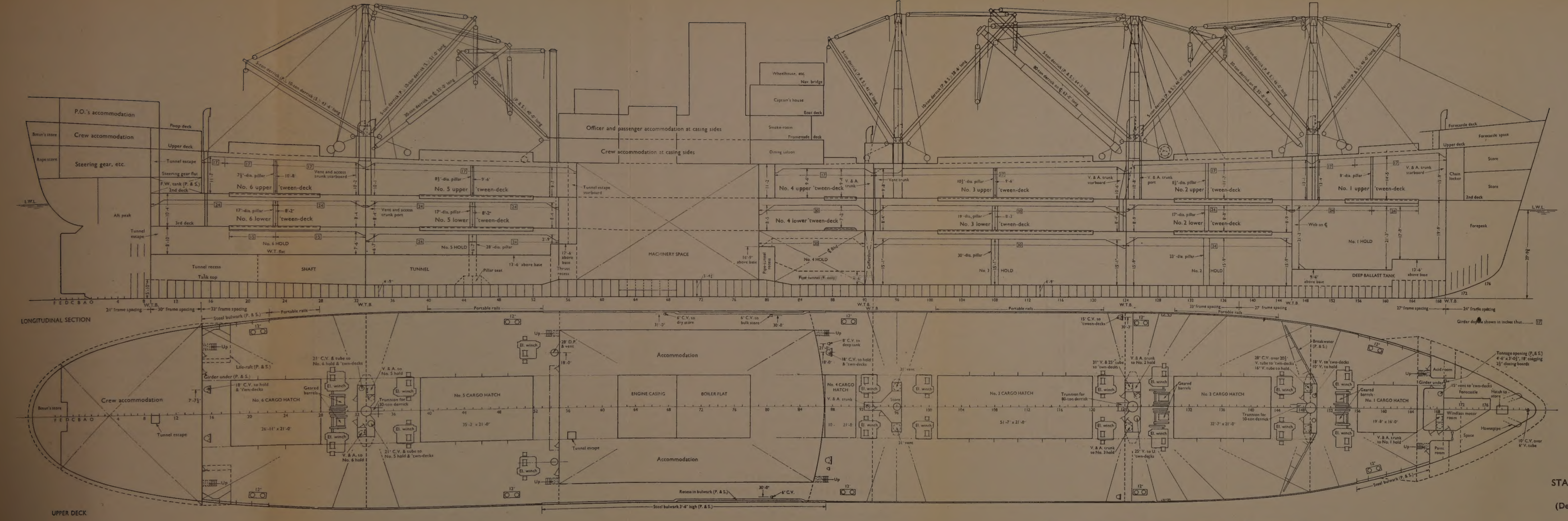
From the ship-design aspect, it may be uneconomic to fit elaborate and expensiv mechanical gear which would only be used intermittently and probably prejudice th earning potential of the vessel.

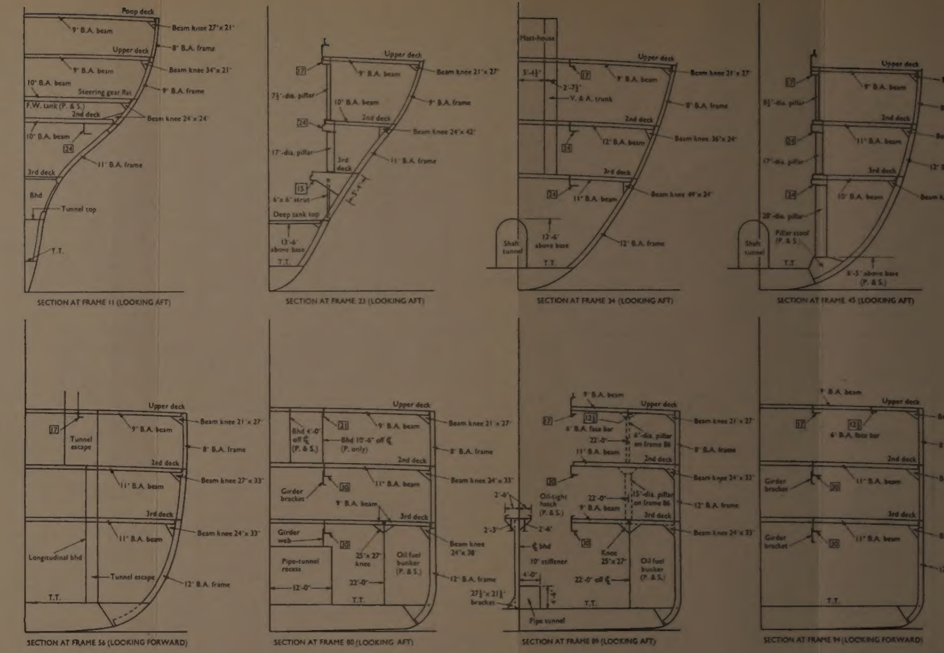
It might be imagined that it would be cheapest to deal with cased fruit, and othe small items of uniformly packed general cargo, by shore elevator and conveyor gea similar in principle to that used for handling bananas.

It appears at this stage that fundamental change is unlikely in the design of ship for the carriage of general cargo on liner service.

For new bulk trades and new ports, the premises mentioned earlier on do no wholly apply. A more stable pattern for the world movement of bulk cargoes perhaps emerging and, should the trend continue, it seems probable that ports wi be called upon to provide facilities for new types of ships which will be designed fo fully mechanized cargo handling.

The Paper, which was received on the 18th December, 1955, is accompanied b one sheet of diagrams, from which folding Plates 1 and 2 have been prepared.





K E Y

B.A.	denotes	bulb angle	L.	denotes	lower	P. & S.	denotes	port and starboard	V.	denotes	vent
Bhd	,,	bulkhead	M.H.	,,	manhole	T.E.	,,	trunk escape	V. & A.	,,	vent and access
C.V.	,,	cowl vent	O.A.	,,	ordinary angle	T.H.	,,	trimming hatch	W.B.	,,	water ballast
D.P.	,,	derrick post	O.F.	,,	oil fuel	T.T.	,,	tank top	W.T.	,,	watertight
F.W.	,,	fresh water	O.T.	,,	oil tank	U.	,,	upper			

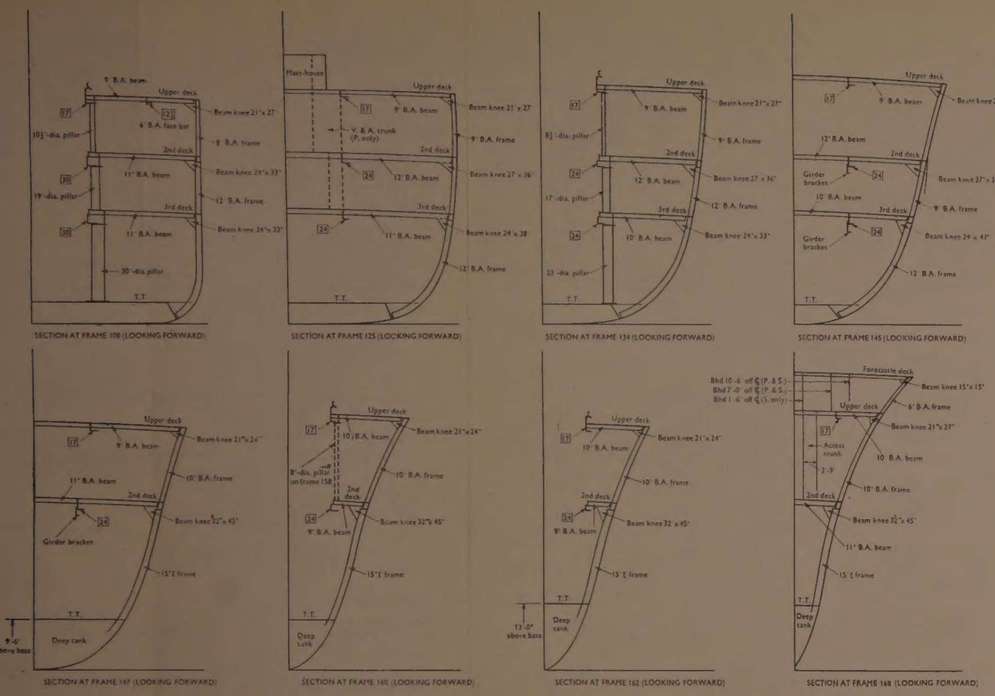
Scale: 1 inch=25 feet

FIG. 1a.—CARGO STOWAGE
STANDARD 15-KNOT CARGO LINER
(465' × 64' × 42'-8")
(Deadweight capacity = about 11,750 tons)

J. A. H. LEES

Hugh Collins & Sons, Limited: London.

GENERAL CARGO HANDLING: DESIGN OF SHIPS



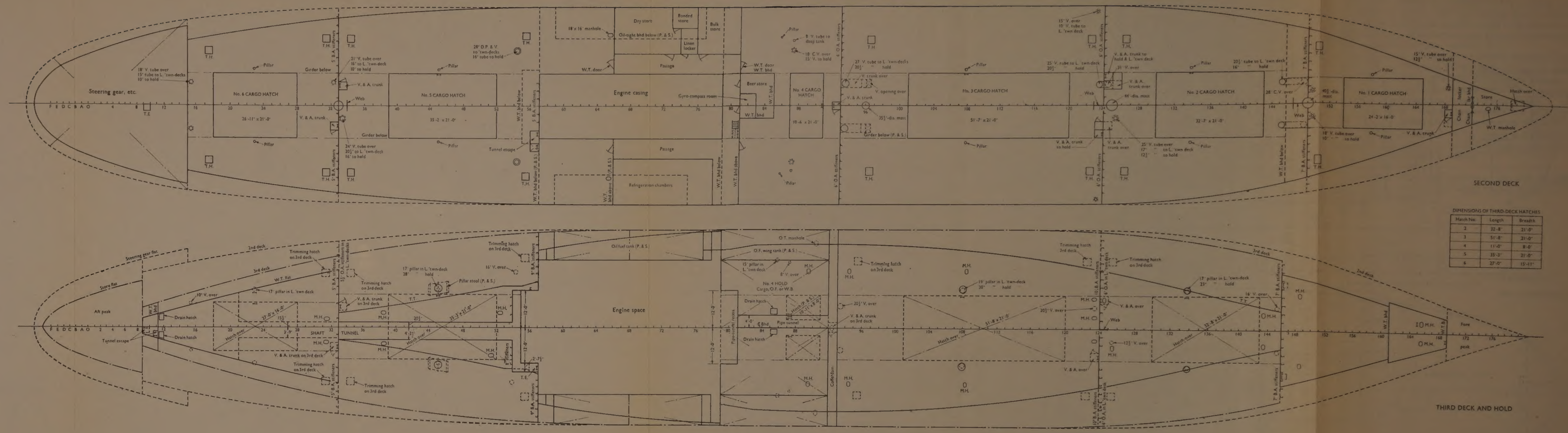
KEY

B.A.	denotes	bulb angle	L.	denotes	lower	P. & S.	denotes	port and starboard	V.	denotes	vent
Bhd	,,	bulkhead	M.H.	,,	manhole	T.E.	,,	trunk escape	V. & A.	,,	vent and access
C.V.	,,	cowl vent	O.A.	,,	ordinary angle	T.H.	,,	trimming hatch	W.B.	,,	water ballast
D.P.	,,	derrick post	O.F.	,,	oil fuel	T.T.	,,	tank top	W.T.	,,	watertight
F.W.	,,	fresh water	O.T.	,,	oil tank	U.	,,	upper			

Scale: 1 inch=25 feet

Feet 10 5 0 10 20 30 40 50 60 70 80 90 100 feet

J. A. H. LEES



DIMENSIONS OF THIRD-DECK HATCHES

Hatch No.	Length	Breadth
2	32'-8"	21'-0"
3	51'-8"	21'-0"
4	11'-0"	8'-0"
5	35'-3"	21'-0"
6	27'-0"	15'-11"

FIG. 1b.—CARGO STOWAGE
STANDARD 15-KNOT CARGO LINER
(465' × 64' × 42'-8")
(Deadweight capacity = about 11,750 tons)

William Clowes & Sons, Limited: London.

Maritime Paper No. 33

CIVIL ENGINEERING STRUCTURES

by

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SYNOPSIS

In this Paper attention is drawn to some aspects of the layout and construction of dock roadways and railways, quayage, transit sheds and warehouses, with special regard to their effect on the handling of general cargo.

Some of the requirements for efficient road, rail, and shed working are set out briefly; the Figures in the Paper are intended to illustrate in very general form the main features mentioned.

The necessity to utilize space to the utmost advantage is a primary factor in the layout of dock estates, and it is pointed out that the best engineering design must on occasion give place to other considerations which may equally influence the prosperity of an undertaking. This is particularly so in the case of sheds, where ease of operation must be related to the cost of the facility provided and its revenue-earning capacity.

Since so much depends on the type and volume of goods handled each port, and even each berth, may call for its own particular layout. Considerations of the loadings imposed by buildings, roadways, rail tracks, cranes, and other mobile appliances also play an important part in the design of quay structures.

The Paper discusses only the main essential requirements for the handling of the more normal types of general cargo which pass through British ports today.

INTRODUCTION

SOME of the principal factors which must be known or carefully assessed in preparing any layout for general cargo handling are:—

(1) The total area available.
(2) The types and volume of cargo to be handled.
(3) The extent to which export as well as import cargo must be catered for.
(4) The methods to be used for discharging and loading cargo.
(5) The amount of cargo requiring transit, short- and long-term storage.
(6) The amount of cargo to be handled by road, rail, and barge.
(7) The extent to which direct working between ship and shore transport or barges will take place.

These factors are so variable that it is obvious that nothing in the nature of a standard specification can be drawn up, and that each port—indeed almost each berth—will require individual consideration and a particular layout.

The forms of transport to be used in clearing and bringing goods from and to berths and sheds have naturally a tremendous bearing on the layout of dockside areas. Indeed, except for certain considerations related to the design of sheds, warehouses, and other buildings, transport methods almost wholly determine the layout to be adopted. It is certain, for example, that many ports today operate at less than full efficiency because they were primarily designed to deal with a very

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high percentage of rail-borne traffic and cannot readily be adapted to cope with the vast increase which has, comparatively suddenly, taken place in the use of road transport.

Most modern docks handling a large and steady volume of general cargo require:—

(1) Good main and access roadways.
(2) Good internal and main-line railway facilities.
(3) Extensive, easily worked transit (and often warehouse) accommodation.
(4) Fast-working cranes of adequate capacity and out-reach (say, 3 tons at not less than 65-ft radius); also modern mechanical appliances for handling cargo on quays and in sheds.

Since space is almost invariably of utmost value in and near waterside areas, there should never be preconceived ideas about layout. Once the main commercial requirements have been made known, the engineer should prepare, within the limitations of any site, as many variations of layout as will reasonably fulfil these demands. No doubt the best engineering layout will ensure the smoothest and quickest means of working; but with these desirable provisions must be coupled the greatest revenue-earning capacity and consideration for the needs of possible future extensions and developments. The prosperity and efficiency of a port are sometimes gauged by the amount of cargo passed over a unit length of its total quayage per unit of time, but it is surely a better guide to take into account also the total area occupied by all adjuncts to the quayage. No such figures on the latter basis seem to be available (and admittedly it would be difficult to arrive at a common method of assessment for all ports), but figures varying from 120 tons up to more than 300 tons of cargo per linear ft of quay per annum seem general in Britain. These figures—while allowing that the types of cargo handled have a marked effect—bear out the need for careful utilization of space, since unless it can be shown that the occupation of greater area will result in a clear increase in the total tonnage of goods handled, or an equivalent reduction in operating costs, the value of the area occupied may be greater than the benefits obtained from improved layout.

Dock roads

Roadways throughout dock areas must be able to handle inward and outward cargo to the same extent as it is possible, or necessary, to handle such cargo at the berths and sheds. They should be of ample width to allow the free passage of vehicles, and also allow standage space for vehicles waiting to take their turn at berths or sheds. A width of not less than 40 ft is generally found necessary, but too great a width is undesirable since it often leads to confusion and difficulty of control. Preferably, where road transport is heavy, the roadways themselves need only be of sufficient width for free passage of vehicles and there should be a series of standage areas adjacent to berths and sheds with a form of "call-in" system so that vehicles can be brought up to their required place in the order wanted, or as vehicles which have already completed their duty move away from the dock area (Fig. 2, Plate 3).

With the growing use of road transport and mobile mechanical equipment, it is very necessary that dock roads should be well constructed and maintained. In many cases it is not possible to avoid running plant (such as fork-lift trucks) over main and access roads, sometimes for appreciable distances, and since these and similar appliances are not usually intended for operation except on smooth hard surfaces much damage and costly maintenance may result if roadways are not of a good standard.

FIG. 7.—INTERIOR OF GENERAL CARGO WAREHOUSE (AND BASEMENT WINE BOND) SHOWING COLUMN SPACING AND NATURAL LIGHTING

FIG. 8.—FORK-LIFT TRUCK OPERATING ON SECOND-FLOOR ROOF OF COMBINED TRANSIT SHED AND WAREHOUSE—CONVEYING BAGGED GOODS TO SMALLER TRUCK FOR STACKING ON FOURTH FLOOR

Fig. 9.—Basement wine bond beneath general cargo warehouse—showing artificial (fluorescent) lighting

Whilst road vehicles are not so restricted as locomotives in regard to movement on gradients and curves, it is desirable to keep these to the minimum, particularly curves, which should be not less than 40 ft on the inside radius, since otherwise some difficulty may be experienced in handling long and heavy vehicles.

Care should be taken to avoid undue congestion at points where there is unavoidable concentration of road traffic; for example, where it is the custom for vehicles leaving dock areas to be checked and examined some delay necessarily occurs, and near such examination points, therefore, there should be uninterrupted access to and from the main highways or their approaches. A possible source of obstruction is a level crossing (either main line or dock railway) near an examination point, and this should certainly be avoided if at all possible.

Adequate lighting of dock roads is very important, particularly in areas where there is also heavy rail traffic. Roadways should have well-defined kerbs or edgings and be clearly signposted with route and warning notices, as also should access roads to berths and sheds, which must be free from obstructions such as switch levers. The berths, sheds, and warehouses should be clearly marked so as to be easily identifiable from a distance.

Dock railways

As in the case of roads, dock railways must be capable of handling inward and outward traffic to the same extent as the berths and equipment.

Because of the comparative inflexibility of rail tracks once they are laid, especially if "paved-in," it is advisable to ensure that the facilities provided will be sufficient, since otherwise extensions may later prove either impossible or extremely costly. For example, unless the volume and ratio of road and rail traffic on any section of quay is well established and unlikely to alter materially, it would be well to consider in the case, say, of a quay layout requiring at the time only two tracks, the provision of a third track on the space allocated for road transport. This third track would not interfere with the use of the road, but should rail operations at any time increase beyond original requirements the track is there to deal with them, whereas it might be a major work to install a new track on a constructed quay. For the same reason, sorting grids both for internal traffic and at the exchange sidings, where traffic is passed to and from the main-line railways, must be of adequate capacity.

Sorting grids are preferably sited well clear of the berths and sheds, but small standage grids should be laid down near these so that full and empty wagons may be removed from or placed at the berths and sheds at convenient times, thereby reducing delays to ship working and eliminating the waste of having locomotive power always in attendance for the immediate haulage of wagons to and from the main grids (Fig. 2, Plate 3).

Generally, all rail tracks should be paved-in wherever there is a likelihood of road transport being used.

It is advisable to allow over-standard clearances on approach tracks to any areas where out-of-gauge loads may have to be handled. Arrangements such as are sometimes possible on main-line railways for dealing with these loads are not always possible on docks, where space is generally more restricted by the presence of permanent and substantial buildings and where, also, the tracks may be paved-in.

Curve radii should be as great as possible wherever locomotives are to be used; the type and size of locomotive may have a material effect on the figure to be adopted. For instance, it has been found that diesel and diesel-electric locomotives will distort

curves which can be negotiated by steam locomotives of comparable size without any distortion taking place.

Gradients must be kept as low as possible; unless movement of wagons by gravity is to be employed in any area, a gradient of 1:260 should not be exceeded where wagons are to be left standing.

Level crossings, apart from almost invariable difficulties of maintenance, should be kept to the minimum since they are bound to create delays where there is a substantial volume of road traffic.

Quay layout

Once the ratio between road and rail transport has been determined as accurately as possible, the facilities to be provided for these on the quay and how they should be laid out in relationship to ship, shed, and cranes, can be decided. Much will, of course, depend on the extent to which goods are to be handled direct between ship and shore transport and the extent to which they are to pass through transit shed or into short- or long-term storage, the volume of export as well as import goods to be handled, to what extent ships' gear is to be used, and to what extent mechanized appliances will be employed.

Unless the volume of goods for rail is very small at least two tracks are necessary on the quay and it is more usual to provide three. In some cases it has even been considered necessary to lay a fourth track, but this is rather unusual and is intended for dealing with exceptional cargoes, which perhaps could not properly be described as "general." However, as already mentioned, if road space has to be provided on the apron, the additional track can be laid therein without either impeding the normal use of road transport or increasing the width of the apron.

If three tracks and a roadway (with or without a fourth track incorporated) are necessary, the apron width should be not less than 65 ft measured from edge of quay to face of shed. This distance allows ample space between landward (third) track and sheds for road vehicles, which must be able to stand well clear of tracks and shed openings, and in the case of two or multi-storey sheds being used will easily allow cranes of 65-ft working radius to handle goods on to or off platforms on the upper floors (Figs 2 and 3, Plate 3).

In order that cranes may have the greatest possible out-reach over holds of vessels, and in some cases be able to handle goods across ships to barges, the outer crane rail should be placed as near the quay edge as conditions will permit, about 6 ft being usually sufficient for clearing bollards and allowing for the passage of ships' ropes, etc. With this arrangement the outer rail track can still be laid near enough to the quay edge for direct work by ships' derricks to railway wagons (Fig. 2, Plate 3).

Where there is a series of berths "in line," the rail handling to each berth is performed by using one of the tracks as a through track serving all the berths, or providing turn-outs at intervals of two or more berths to through tracks laid clear of the berths and sheds, or providing turn-outs at each berth—or some combination of these methods. The first method is economical of space, but in the case of a heavy flow of rail traffic is undesirable since it involves the loss of one track as a loading track and also causes interruption to the free use of adjoining berths where quay mechanical appliances may be in the process of handling goods across the tracks to shed. Where possible, each berth and its shed accommodation should be independent for rail working. Although this may mean wider spacing of sheds, the intervening area need not be excessive and is invariably found useful for stacking packages which

do not require covered storage, for the assembly of export cargo, and also for use by road vehicles, particularly if the ends, or one end, of each shed can be adapted by means of a platform for road loading. The desirability of providing such open areas near transit sheds is often lost sight of, and their absence may mean unnecessary and wasteful use of covered space (Fig. 2, Plate 3).

If road transport is extensively used on the quay apron, obstructions should be reduced to the absolute minimum. For this reason, there is much to be said for the use of shunting tractors, instead of capstans, for moving rail wagons. It is difficult to assess the relative overall costs of the two methods, but possibly the use of shunting tractors is the more expensive since they require greater maintenance attention and are unavoidably subjected to much rough usage, especially when quay surfaces are wet and track resistances high owing to dirt or other causes. On the other hand, whilst capstans afford a constant and reliable source of power for such haulage they do form obstructions and call for wider rail spacing if safe clearances are to be ensured; they also have the disadvantage of requiring the use of ropes which, apart from breakages, are often a nuisance and to some extent a danger on busy quays.

Quay surfaces must be smooth and hard wearing, with cross-falls only sufficient to ensure proper drainage. With the advent of mechanized equipment the quality of quay surfaces has greatly increased in importance and must include high strength and wearing characteristics, and it should be a principal requirement that they can be repaired quickly and put into use with the least delay after repair or re-laying. The employment of individual flooring units which can readily be lifted and re-levelled or replaced should always receive consideration, since the relatively high initial cost of this system may often be more than repaid by reduction in delays when the quay surface has to be repaired.

Sheds and warehouses

The length of any transit shed is generally governed by the length of berth it serves and since the height to which goods can be stacked is largely defined within limits imposed by the type of goods, reasonable floor loadings, the use or otherwise of mechanical equipment, etc., it usually follows that, if the probable volume of traffic which will use any shed is fairly well known, the necessary width can be determined. Should this width be too great for purposes of efficient and economical trucking or unattainable because of space restrictions, then, apart from whether additional accommodation is required for storage of import or export goods, the two-storey or multi-storey shed must be resorted to (Fig. 4, Plate 4).

Whilst on first principles it would seem obvious that single-storey sheds are the most suitable type, there is in fact no general rule which can be laid down in this matter; the problem can only be resolved for each individual case in consultation with all interests concerned and in relation to all local factors. The divergence of opinion evident between many authorities of many countries on the subject of single versus two-storey transit sheds would merely seem to emphasize that, since no two ports are alike either in physical or operating aspects, what has been proved right at one port may prove to be totally wrong at another.

Consistent with fulfilling its proper functions as a safe coverage for goods, a transit shed should be of the lightest and cheapest type possible without incurring heavy and constant expenditure on maintenance. This applies more particularly to the single-storey type, where light construction is more practicable, since if later it is found necessary to provide greater covered area by the erection of a larger shed, or of a two-storey shed, the expenditure involved will be less than required in the

alteration or demolition of a heavy-type structure. The use of structural steel in two-storey sheds may well be an advantage, since this method often allows greater possibilities than reinforced concrete for internal alterations to be made should operating experience or changes in traffic require them (cf. Fig. 3, Plate 3, and Fig. 4, Plate 4).

Single-storey sheds have the immediate advantage of lower initial cost and greater ease of operation. Possibly the maximum width for normal cargo handling is about 150 ft, although sheds exceeding 200 ft in width have been constructed and found satisfactory (Fig. 5, Plate 4). Before the advent of efficient mechanical equipment for moving goods at quay level, there might have been objections to shed widths of more than 90 ft on the score that they would entail excessive trucking. In the case of export cargo having to be handled in shed at the same time as import, single-storey sheds are frequently found unsatisfactory, since the needs of the two cargoes must to some extent conflict, however carefully laid down.

Whilst there are many arguments in favour of the single-storey shed, space is usually so valuable in dock areas that it would often be bad economy to utilize it for single-storey sheds, since the additional initial and operating costs of the two-storey type might well be offset by the availability of space for other important dock works and facilities. Today, more than ever before, there is a growing demand for space (which can ill be spared) on which to provide car parks, medical centres for dock workers, canteens, lavatory and washing facilities, etc. Furthermore, even though a manageable width of 150 ft or more is available, it may be that the volume of goods to be handled requires greater floor area and so the two-storey shed becomes unavoidable. For transit purposes it is often considered undesirable to exceed two storeys because of the difficulty in arranging that the flow of goods from the various floors can proceed without interruption.

Two-storey sheds almost invariably call for the provision of heavier foundations and in many cases the area has to be piled. This, together with the need for constructing a strong upper floor and installing facilities for deliveries from that floor, greatly increases the cost per square foot of useful floor space. Available figures for the costs of the two types of shed would seem to establish that for equal useful floor areas and generally similar forms of construction a two-storey shed will be approximately 1·60 to 1·80 times the cost of a single-storey shed, allowance being made for the cost of appliances necessary for the delivery of goods landed on the upper floor. The figures of comparative operating costs which are available are insufficient for useful study; but, whilst those for two-storey sheds are certainly higher, there seems little doubt that the skilful management of this type of transit storage can generally show it to be an economic proposition in any overall assessment.

Much has also been said on the subject of shed columns. The advocates of the single-storey building point out the advantages of being able to reduce the number of columns to the absolute minimum, and indeed in many cases being able to dispense with them entirely, thereby leaving large unobstructed floor areas on which mobile plant can operate with complete freedom. But since the construction of large spans, whatever the method employed, will undoubtedly increase the shed cost, it is necessary to consider carefully whether the advantages to be gained are always sufficient to outweigh the greater cost. Absence of floor obstruction is a very commendable objective, but it is surely not imposing an unreasonable restriction if columns are spaced at intervals of, say, not less than 30 ft. Such spacing would generally afford ample room for the operation of mechanical plant, if it is being used with proper care, without really affecting its speed. This does not imply that 30 ft column spacing is

put forward as the maximum in every case; with certain types of cargo it may certainly be both necessary and advantageous to have much wider spacing, but there seems little point in incurring the additional cost if 30 ft spacing gives an economical design and satisfies other considerations. Present-day methods of construction—prestressed concrete for example—allow the provision of far greater unobstructed floor areas than were formerly possible; these methods, however, should be employed only when it can be demonstrated that a worthwhile gain in speed and a lower cost of handling goods will result. It is doubtful whether this is always kept fully in mind and there is perhaps a tendency for engineers to exhibit advances in technical skill and constructional methods, and for traffic operators to over-emphasize the benefits of these advances, in cases where closer column spacing would be perfectly manageable at less cost. With the stated 30 ft minimum spacing, the Author has found no evidence of real difficulty or loss of shed space or speed in the working of the more usual types of general cargo (Fig. 6, Plate 4, and Fig. 7).

In the case of two-storey sheds, the upper storey should be stepped back about 12 to 15 ft on the waterside to provide a continuous platform for the handling of goods in the same manner as on the quay (Figs 2 and 3, Plate 3, and Fig. 8). Methods of delivery from upper floors must be such that they can adequately handle the type and volume of goods stored. For general cargo, wooden and gravity roller chutes and lifts of 30 cwt to 2 tons capacity for packages which cannot be handled on chutes are the most common means of delivery. As well as the number of such appliances, it is important to determine their positions in order that deliveries can be effected to road and rail transport inside or outside any shed with the least amount of handling and without impeding work on the ground floor.

Shed floors must be smooth and hard wearing, with no floor slope exceeding 1:100, and the waterside edge should be at quay level to allow the use of mobile equipment from quay into shed. The remarks regarding ease and speed of repair to quay surfaces apply with equal force to shed floors, which ought to be strong enough to allow the free use of fork-lift trucks and similar appliances on upper as well as ground floors (Fig. 8).

For general cargo work a clear height of not less than 16 ft is required in transit sheds and unless a shed is very narrow, or artificial lighting is to be used at all times, a clear height of 20 ft would be more desirable. If it is required to use mobile cranes then the height in the sheds, and at some or all doorways, would have to be increased to about 24 ft so that the cranes may travel with raised jibs. The development of "unit-load" cargoes may have a considerable effect on the heights to be provided, but the figures given would seem to be suitable and difficulties are more likely to arise through insufficient floor strengths to carry the fairly concentrated loadings imposed by such cargoes and the machines which must be employed to stack them.

Despite difficulties of maintenance and in securing watertightness, continuous sliding doors are advantageous, particularly on the waterside of transit sheds. On busy quays it is a distinct advantage to run trucks or any appliances the shortest possible distance between their point of loading and point of entry into a shed, and this is not possible with only a limited number of shed openings.

Loading platforms at the rear of sheds should be 10 to 12 ft wide, and any outside platform and the rail track alongside should be under a cover of sufficient extent to shelter road vehicles which may also use the platform (Fig. 2, Plate 3). It is often desirable to arrange for road loading platforms at the ends of sheds, since goods—particularly from upper floors—can at times be more conveniently handled there. A second rail track can be provided at the rear of a two-storey transit shed for direct

working of goods by cranes or goods hoists from and to the upper floor. A rather attractive arrangement, whereby handling upper-floor goods can be performed under cover without necessarily interfering with the ground floor working, is to construct a second loading platform, on the rear line of shed columns, served direct by goods lifts. This arrangement also possesses the advantage of allowing, to some extent, simultaneous road and rail working (Fig. 2, Plate 3).

In addition to the usual shed offices, it is becoming increasingly necessary to consider allocation of space for the accommodation of mobile plant, pallets, and other gear used in ship work; also special sections for the custody of certain highly pilferable goods. If definite provision is not made for these items shed floors tend to become untidy and obstructed, with increased possibility of accidents, and pilfering and loss of gear may result as well as increased fire risk.

Evenly distributed natural and artificial shed lighting is essential, and in the design of sheds with more than one floor care must be taken to ensure that loss of natural light on the ground and intermediate floors is reduced to the minimum. Interior decoration of sheds can play a large part in the efficiency of both natural and artificial lighting; walls, roofs, and columns should be treated in light colours. Artificial lighting should be designed with the object of giving a reasonably uniform intensity at floor level. Obviously the intensity to be provided will vary with the nature of the work to be done in any shed, but for general work a figure of 1·0/1·50 ft-candle would appear adequate, although in some cases this would have to be greatly increased (say up to 3 ft-candles or more) and the lower figure is perhaps insufficient as an original provision owing to the fairly rapid deterioration in efficiency which will take place (Figs 7 and 9).

Warehouse lighting may vary within very wide limits depending on the goods stored and the methods of operation.

Many of the considerations respecting transit sheds—strength of floors, column spacing, etc.—apply equally to warehouses. It is often advisable to design for greater headroom in warehouses than in transit sheds since, usually, goods can be stacked higher for warehouse than for transit storage. Space occupied by the use of palletized goods may also tend towards the provision of increased clearances.

It is not usually desirable to have warehouse storage superimposed on transit floors. Although such a system possibly affords the most convenient and economical means of warehousing near ship's side, it is too often found that warehouse operations conflict with the working of transit floors. There are, however, certain cases where the arrangement can prove quite workable, such as where short-term storage is made available in the upper floor for goods waiting to be handled to ship, provided that a discharging ship can remain at the berth to load its outward cargo.

Wherever practicable, dock warehouse accommodation should be sited clear of berths and transit sheds; but in addition to adequate road and rail access, the possibility of erecting connecting bridges to the waterside sheds should be considered if the distance between warehouse and berth is not too great. This arrangement is of value when part of the warehouse space is used for export goods which can then be taken to berth for shipment without further need of road or rail transport.

The Paper, which was received on the 20th December, 1955, is accompanied by three photographs and five sheets of drawings from which the half-tone page plates and folding Plates 3 and 4 have been prepared.

GENERAL CARGO HANDLING: CIVIL ENGINEERING STRUCTURES

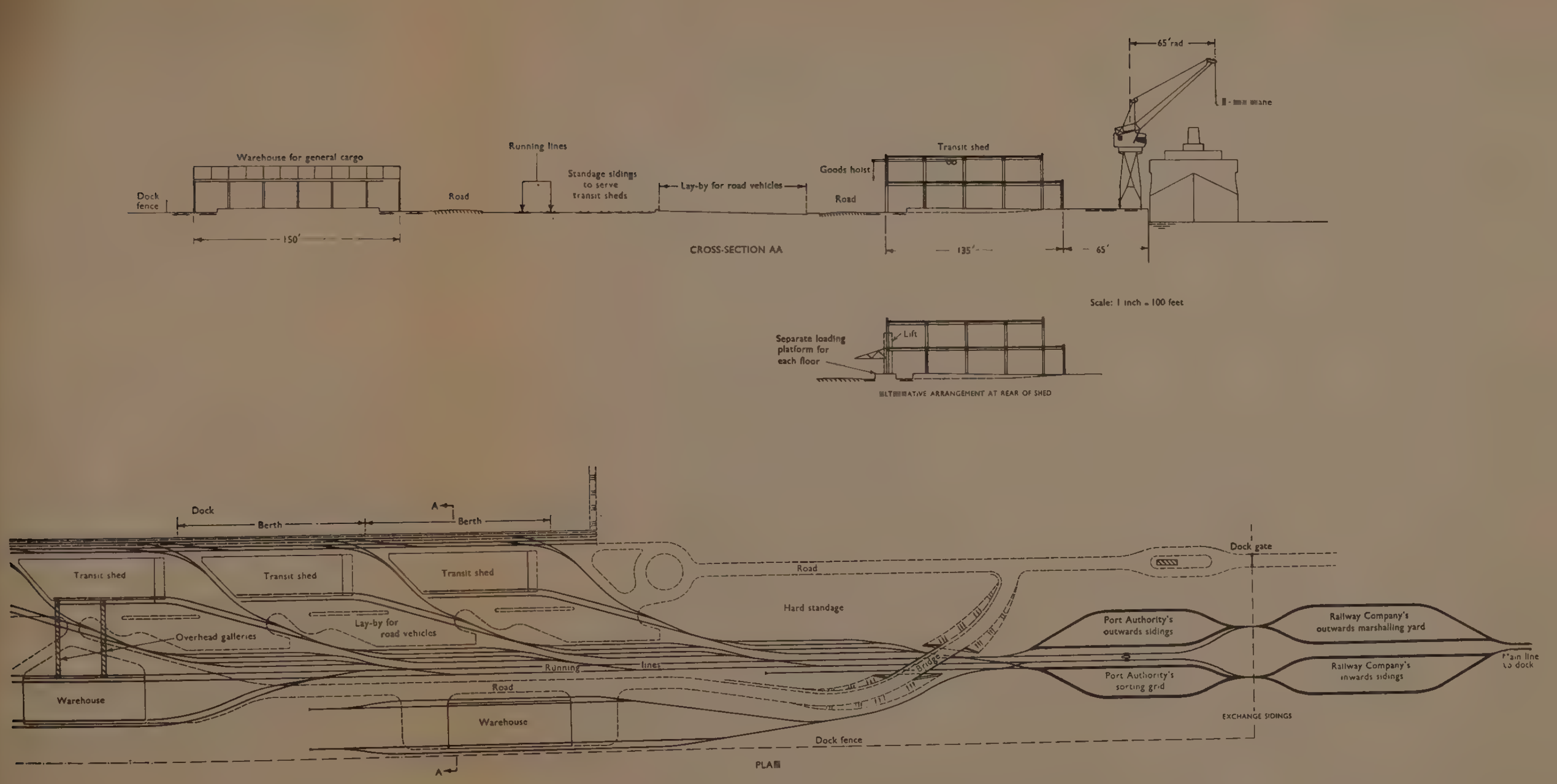

FIG. 2.—DIAGRAMMATIC LAYOUT OF QUAY
(Showing roads, rail tracks, sheds, and warehouses)

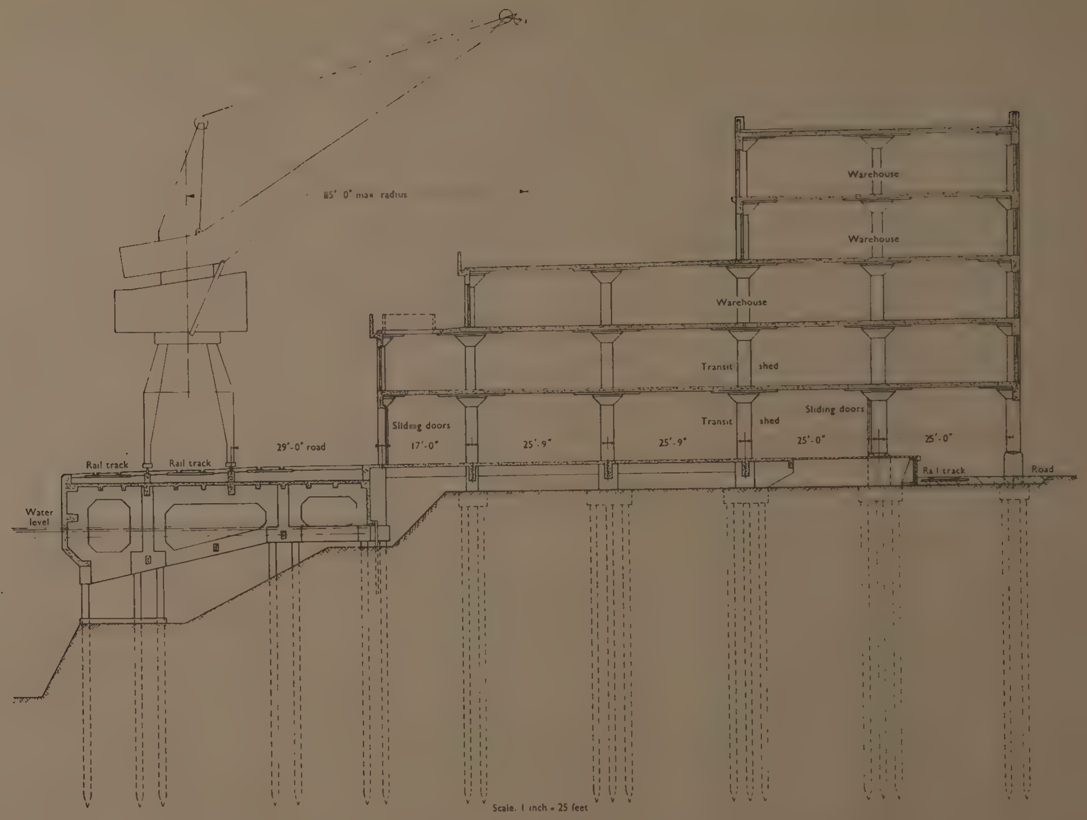

FIG. 3.—CROSS-SECTION OF COMBINED MULTI-STOREY TRANSIT SHED AND WAREHOUSE

N. A. MATHESON

William Clowes & Sons, Limited: London.

GENERAL CARGO HANDLING: CIVIL ENGINEERING STRUCTURES

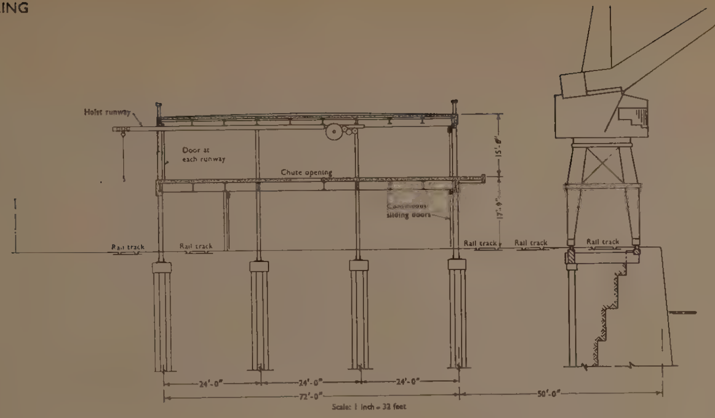

FIG. 4.—CROSS-SECTION OF TWO-STOREY TRANSIT SHED ON RESTRICTED SITE

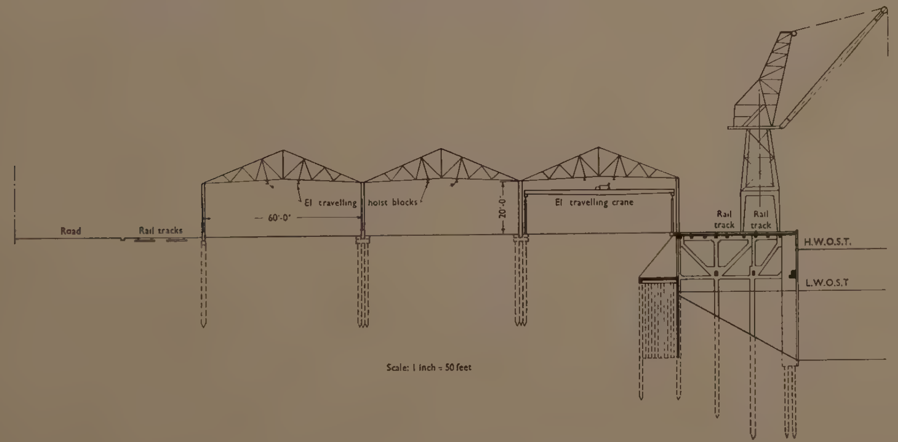

FIG. 5.—CROSS-SECTION OF TYPICAL SINGLE-STOREY TRANSIT SHED

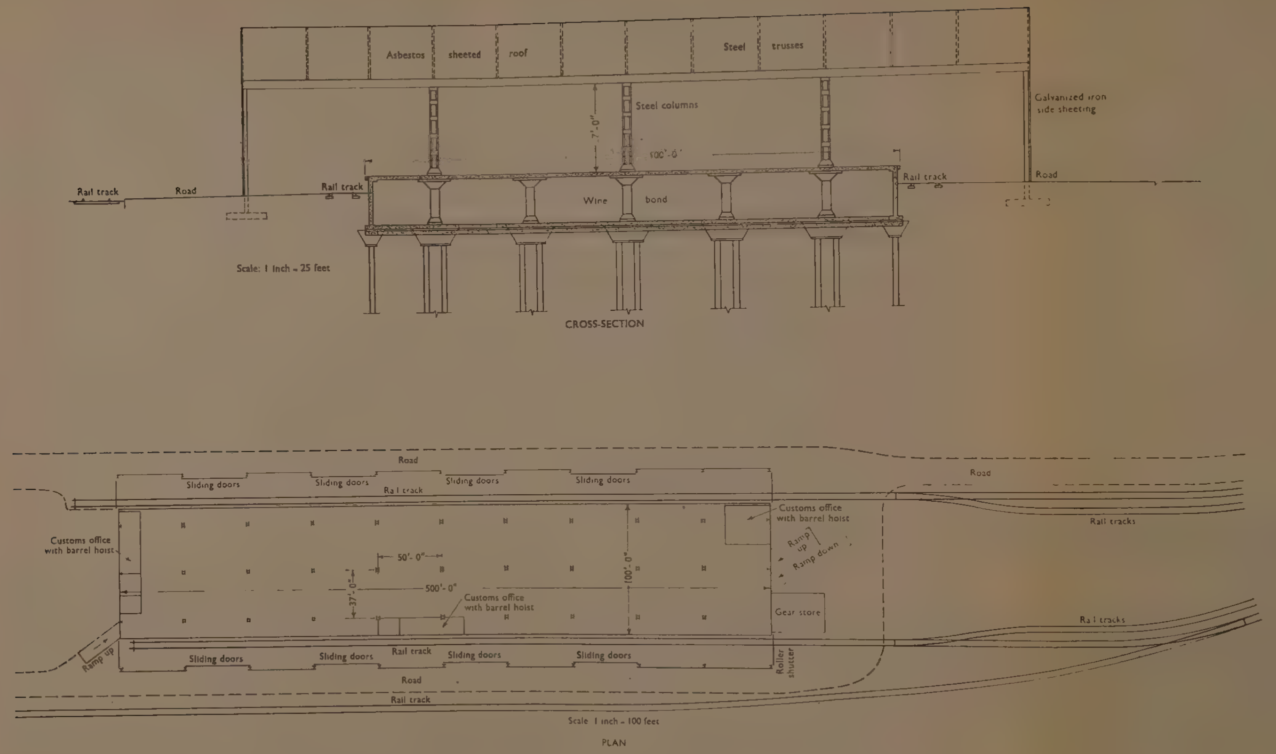

FIG. 6.—GENERAL CARGO WAREHOUSE AND BASEMENT WINE BOND

Maritime Paper No. 34

SUPPLY AND MAINTENANCE OF MECHANICAL EQUIPMENT

by

*** John Caldwell Shire, A.M.I.Mech.E., A.M.I.N.A.**

SYNOPSIS

The Paper deals with the method of selecting mechanical-handling equipment, and illustrates some modifications carried out on standard production machines to make them suitable for port work.

Reference is made to running costs of various types of equipment, to chain gear, and to design of hand and lifting appliances.

The problem of maintenance, attendant on the extensive use of mobile handling equipment, is dealt with by describing a typical organization which has proved itself effective in operation.

Introduction

Until early in this century almost the only important mechanical appliances in general use for cargo handling were the hydraulic quay and wall cranes, and the ship's winch. During the past 50 years these have been progressively replaced by electric cranes, and a wide range of other mechanical equipment has been introduced to general use. The aim of all these machines is to increase speed of handling, due regard being paid to care of cargo and the safety of operators, but the problems of maintenance attendant on the large-scale use of mechanical equipment have not always received sufficient attention.

The modern ship berth dealing with a varied range of general cargo is now equipped with quay, wall, or roof cranes, mobile cranes, fork-lift trucks, electric platform trucks, conveyors, and the wide range of lifting gear and hand appliances required to utilize fully the mechanical equipment.

In the first section of the Paper, the supply and selection of the plant is dealt with, specific examples being given; the second section is devoted to maintenance of the mobile equipment.

The supply and selection of equipment

The design and manufacture of handling plant has of necessity become a highly specialized industry. The dock engineer cannot hope to be a specialist in these fields, and he has therefore, when purchasing equipment, to utilize the knowledge and technique which the manufacturers have applied in the production of their ranges of standard equipment.

In considering the problem of equipment for cargo handling, the first and obvious essential is to ascertain clearly from the operating departments concerned their basic requirements. Since the cost of manufacturing specially designed equipment is

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invariably high in comparison with that in standard production, it devolves upon the engineer wherever possible to consider these requirements against the background that they can usually be met from normal production channels.

Any machine considered for dock work should be structurally, mechanically, and electrically of robust construction, so designed that maintenance is easy and cheap, economical in operation, easy to drive, so far as possible standard with existing equipment, and built to the requirements of the Factories Acts, docks regulations, other applicable statutes, and the relevant B.S. specification. The machine should be of the most suitable type for the work which it is required to do (i.e., it is not satisfactory to use a fork truck, where a mobile crane would be better). Considerable thought should be given to both maintenance and economy of operation, since these are costs which recur throughout the life of the plant, and the selected machines should be compared under all the above headings.

When a standard production unit does not meet all the requirements, the necessary modifications will have to be specified. It has been the Author's experience that standard plant, occasionally incorporating minor modifications, is generally suited to dock work, and it is therefore proposed to deal briefly with a few of these modifications, which may be of interest to other users of mechanical plant.

Modifications to standard production equipment

The principal and most costly item of equipment for handling general cargo is the quay crane. Crank-luffing electric D.C. portal quay cranes have a proved reliability and will give 20 years' service without a major overhaul. To reduce maintenance costs and to improve the driver's control of the crane and his range of vision, certain modifications to the equipment normally fitted have been specified for future cranes of this type.

The existing cranes have drum-type controllers (Fig. 10, facing p. 264) on all motions with contactor panels for luff and hoist. Recent tests using contactor panels on all three motions and "joystick" type combined master controller for luff and slew, and a similar type controller for the hoist motion have been tried and found to meet with the drivers' approval (Figs 11a and 11b). Drum-controller repairs constitute a major item of electric crane maintenance and it is expected that these modifications will reduce maintenance work to the occasional renewal of contact tips. The rating of the slew-and-hoist control resistances is being increased from 5 to 10 min, and additional ventilation is being provided since it has been found that under certain conditions overheating of resistances occurs. The wiring is being improved by replacing V.I.R. insulation with polychloroprene, and fitting fibre-glass sleeving to all tails connected to resistances. To improve visibility from the cab, a bow front is being fitted. The cost of these modifications is £330.

To obviate the potential corrosion points, which exist at the screwed connexions of the handrailing, tubular dowel-joint type of rail will be used; this will not increase the price of the cranes.

The fitting of tubular jibs of triangular or box construction will reduce the weight of jib and flyweight by about 6 tons, lessen windage, improve appearance, and effect a saving in cost of £160.

In recent years much has been published on the treatment and painting of iron and steelwork to prevent corrosion and minimize painting expenses. In general, preparation by shot blasting or pickling has been recommended. The cost of shot blasting is £500 and £675 for 3-ton and 5-ton cranes respectively. Since cranes now 15 years old are only just being repainted, at a cost of £320, shot blasting appears to be uneconomical at present prices.

The mobile crane is an important item of equipment for cargo handling, and in the Author's experience, the standard types have the essential features for withstanding the heavy duty of dock working. The average annual maintenance costs range from £195 to £230 per crane of 3 to 5 tons capacity. Only minor modifications have generally been considered desirable, e.g., the fitting of tire restrictor rings, metallic tires, four-wheel brakes, upturned exhaust pipes, and additional guarding. It is not considered that there is any special engineering advantage to be gained from the use of diesel-electric instead of diesel–mechanical cranes. The capital, operating, and maintenance costs of the two types are comparable.

For economy of operation the cranes must have diesel not petrol engines. The cost of £1,200 for a recent conversion of two 5-ton petrol–electric cranes to diesel–electric will be saved in less than 5 years by reduced fuel costs even when working only single shift, $5\frac{1}{2}$ days a week.

One instance where modification of a standard machine in more than details was found necessary illustrates what can be achieved while still utilizing normal production machines. The requirements were for a mobile crane to handle and stack sawn timber, working partially on soft ground; it had to be capable of plumbing the outside of a barge, (20 ft out-reach), of stacking 12-ft lengths of timber to a height of 23 ft, two lengths deep under a shed with 30-ft free height, leaving only 15-ft gangways. Fig. 12 illustrates the arrangements and the special jib designed to fit a standard diesel–electric crane. For working on the soft ground, power steering and larger travel motor and generator were specified. To give protection from swinging loads, $\frac{1}{4}$-in. steel cladding was fitted on the front of the cab and underside of the jib, ladder-type protection at the front and top of the cab, and heavy rubber buffers on the corners of the superstructure. Air brakes were specified as an extra precaution in addition to the minor modifications mentioned.

The latest addition in the cargo-handling field is the fork-lift truck. Experience has shown that the leading makes of diesel-powered truck require few modifications to make them into satisfactory dock operating tools. In the Authority's docks a standard production truck with the normal type of clutch and transmission has been in use for some years. Eighteen months ago six trucks fitted with torque-convertor drive were introduced. Whilst this type of drive because of its efficiency characteristics increases fuel consumption (at a cost of £20 per annum), it is preferred to the dry plate clutch since it obviates many transmission troubles occasioned by heavy handling, and has thereby reduced maintenance costs. In addition, the fluid drive has controls similar to those of the battery truck, and minimizes driver fatigue. These trucks have been fitted with a leading motor manufacturer's diesel engine as an alternative to the more expensive and powerful four-cylinder petrol engine normally used, and have behaved splendidly under the arduous conditions to which they are subjected. One development of the fluid drive, a 3-ton truck at 27 in. was the design of a side-extension carriage and long forks to facilitate the handling and stacking of reels of liner board. The extension was necessary to allow for insertion and withdrawal of the forks when stacking, because the original carriage width coincided with the pressure points between reels, and the long forks because the centre of gravity of the 80-in. reels was too near the end of the standard 48-in. forks for satisfactory support. (Figs 13 and 14, and Fig. 25, facing p. 265).

The relative annual costs of operating battery, diesel, and petrol-powered fork trucks of similar capacity are in the ratio of 4:5:8. The actual cost for the 2-ton battery truck is about £400, including maintenance, battery charging, depreciation, and the provision of one spare battery to three trucks. Apart from the economic

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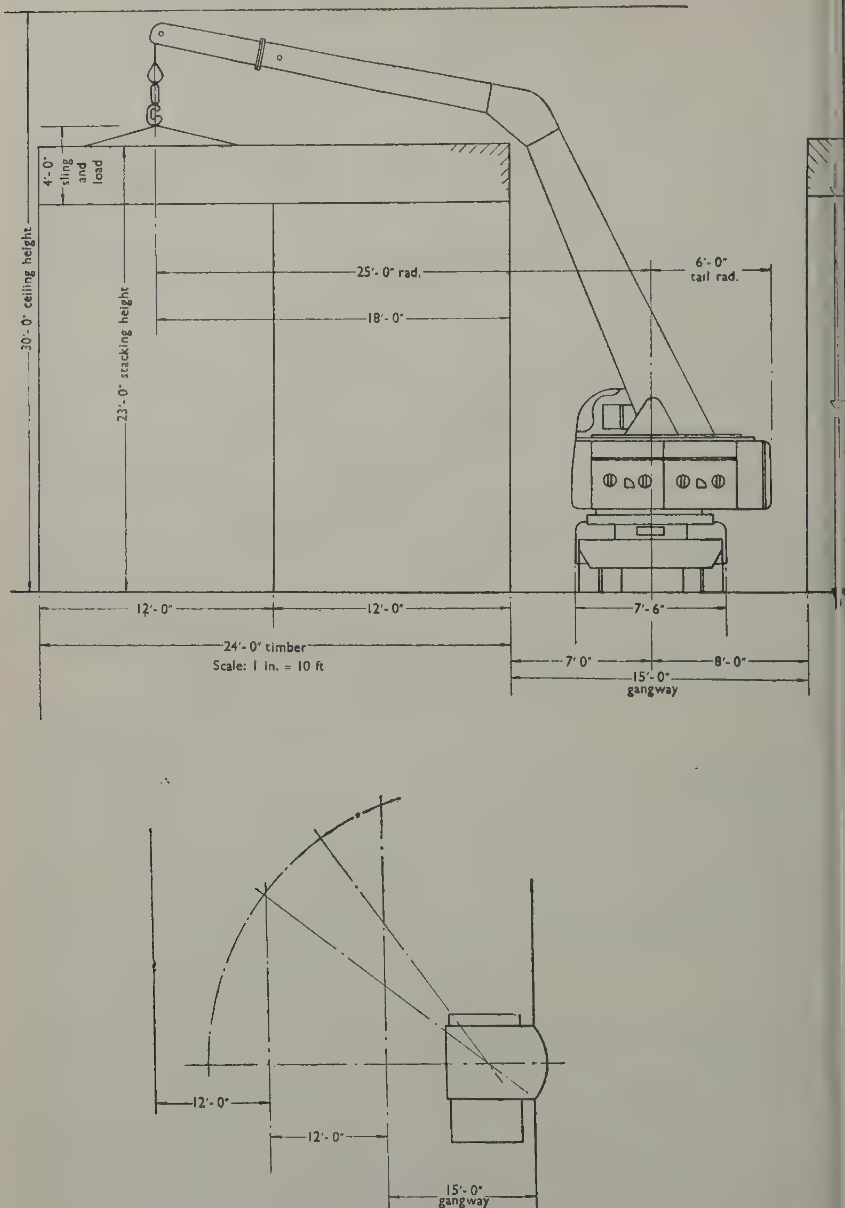


Crane operating in three positions without increasing ceiling height

FIG. 12.—MOBILE CRANE FITTED WITH 26-FT SWAN-NECK JIB AND 6-FT BOLTED EXTENSION HANDLING TIMBER

Crane duties:— 2 tons at 15′–6″ rad. Height of lift 32′
1½ tons „ 20′–0″ „ „ „ „ 29′
1 ton „ 26′–0″ „ „ „ „ 22′
Turning circle 20′–0″

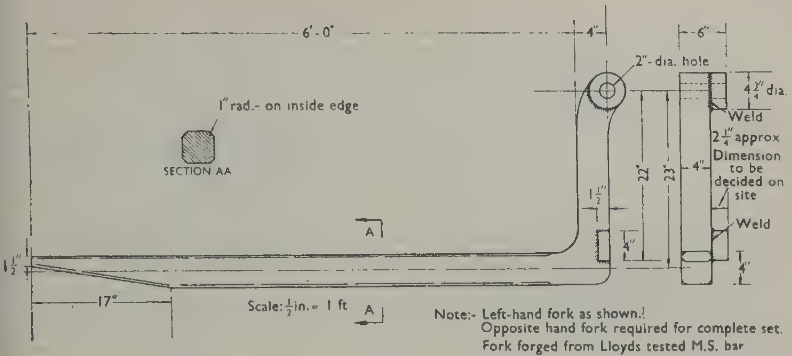


FIG. 13.—EXTENSION FORKS FOR LIFTING PAPER ROLLS
(Safe working load: 3 tons at 2'–3")

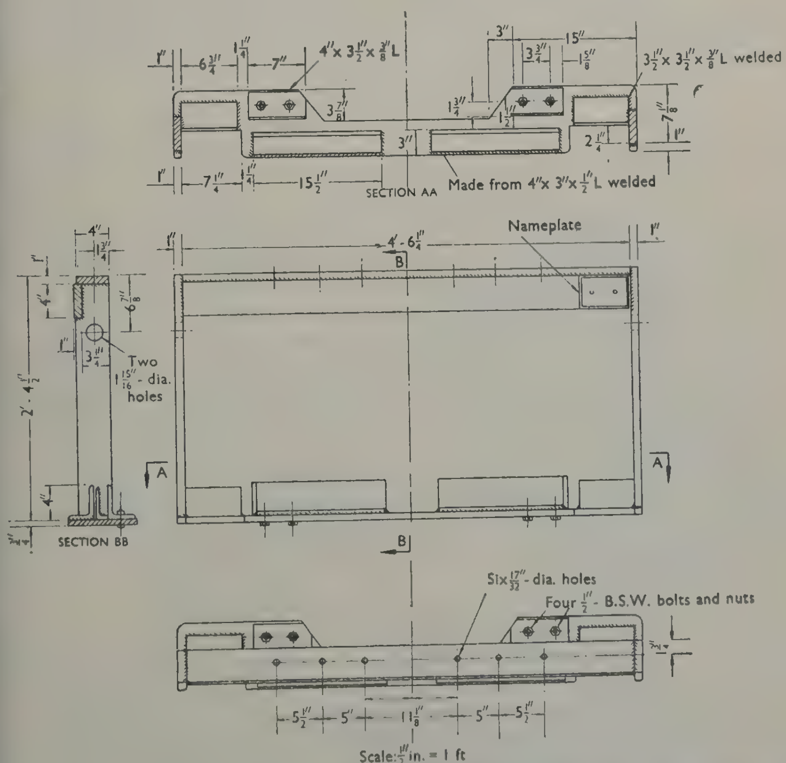


FIG. 14.—EXTENSION CARRIAGE FOR FORK-LIFT TRUCKS AS USED AT WEST INDIA DOCKS

advantage of the battery truck, it is easier to maintain, has no obnoxious exhaust fumes, is silent, and easy to drive. Its disadvantages at present are: (*a*) battery-charging facilities have to be available, which may necessitate long-distance travelling by the trucks or carriage of the batteries, and may make transfer of trucks to outlying areas difficult; (*b*) with the present available design of battery it is not possible with the larger-capacity trucks to achieve a full working day without battery change and (*c*) the operating speeds of the battery trucks are usually rather less than those of the diesel. Whilst it is relatively easy to increase the speeds, this further reduces the battery working hours between charging.

These disadvantages are not insuperable and when they have been overcome, the diesel truck and other diesel-powered appliances may well tend to be superseded in the same way as petrol has been ousted by diesel. The changeover to battery operation would be a natural outcome of the generation of electric power by atomic methods, and it may even be possible within the next decade to harness the atom directly to the handling appliance and dispense with the battery.

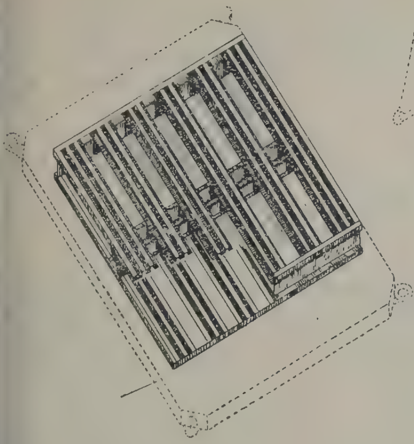
The use of fork trucks necessitates the extensive use of pallets (on average, about 120 per truck). The combination of cargo board and pallet, the development of which is illustrated in Fig. 15, has obvious advantages for ship discharge and cargo-handling work. The combination of steel channel and timber used in its construction has proved the least liable to damage. These pallets cost £7 10*s* 0*d* each; the average expenditure for each pallet returned for repair is £6 18*s* 0*d*, but taking the total holding of pallets into account the average maintenance cost is about £1 4*s* 0*d* per annum per pallet or 16% of the capital cost. From this it is apparent that there is still room for improved designs of pallets.

Tractors and trailers are used generally in small numbers for longer-distance movement of cargo. For dock work, the standard production industrial diesel tractor fitted with shunting attachment is quite satisfactory for both hauling and light shunting. A commercial model was introduced into the Authority's docks 2[illegible] years ago, specially designed more expensive machines having been used previously. The only modifications considered necessary are the fitting of a good trailer brake, extra-deep front buffer plate, lights recessed into the buffer plates, larger rear mud-guards, and a modified towing hitch to suit existing trailers.

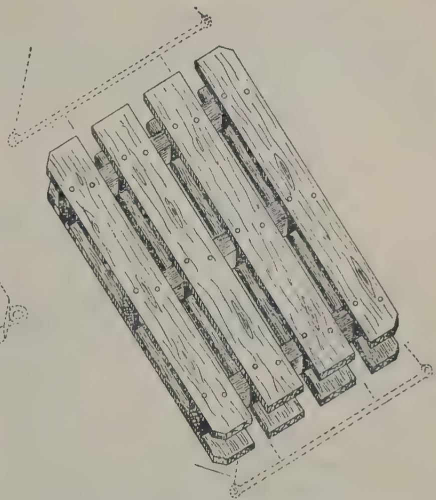
Rail cranes have a limited application, and up to recent years have generally been steam powered. The operating costs for 3-ton steam and diesel models are about £10 and £4 per week of 44 hours respectively, and the diesel has a higher availability than the steam. The capital costs of the two are steam £4,000, diesel £5,500. These figures clearly indicate that it is not economic to buy a steam crane and that it is frequently an economy to purchase a new diesel crane when an old steamer is in need of an extensive overhaul and a new boiler. Investigations are being carried out on the conversion of existing steam cranes to diesel-hydraulic with hydraulic motors coupled to the gear shafts; these may in many cases obviate the economic cause for the new purchases.

Conditions arise where standard equipment cannot be satisfactorily used. In one recent case, additional cranage was required to supplement existing 30-cwt crank luffing roof cranes operating on the road side of three-storey sheds, which have staggered loopholes on the first and second floors. The men working cargo from the flaps inclined to keep inside the shed, which resulted in the driver's visibility of his hook being restricted. The cost of the roof cranes was £8,000 each; this was considered high in relation to the revenue which could be expected from their installation.

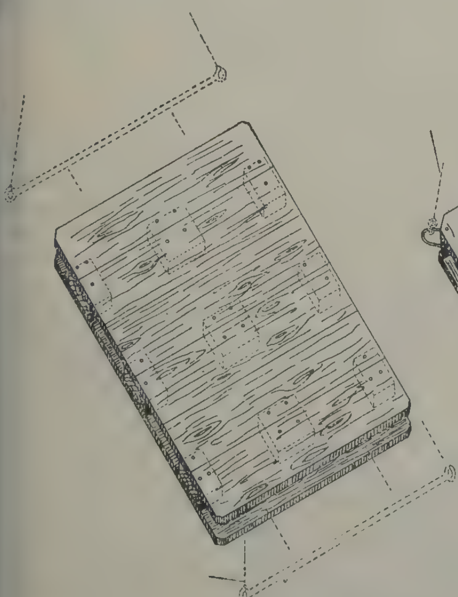
A roof transporter incorporating standard components (gear boxes, electrical



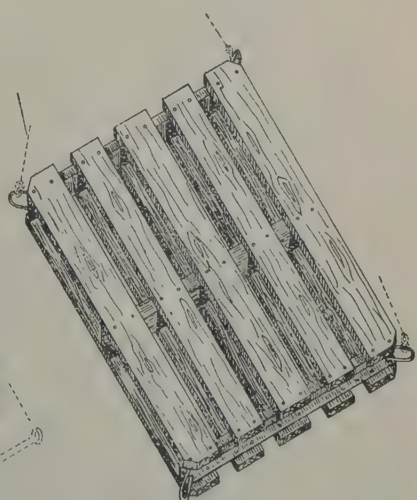
(a) Method of lifting was to place pallet on a normal landing board
(length 4′–0″ × 4′–0″ wide)



(b i) Method of lifting was to insert steel bars on wire straps under wings
(length 6′–0″ × 3′–11″ wide)



(b ii) Method of lifting was to insert steel bars on wire straps under wings
(length 6′–0″ × 4′–0″)



(c) Method of lifting is to use a bunch of four hooks on a central ring
(length 6′–0″ × 4′–5½″)

Fig. 15.—Evolution of stevedores' pallet

equipment, etc.) was designed. It has the same operating characteristics as th crane, but is controlled from a pendent push-button panel, which is retractable fo positioning at either level of loop-holes. (Figs 16 and 17.) The machine cos £5,000 and is preferred to the crane by the operators. The original specification and design called for speeds of :—

Hoisting } two speeds	. . . .	100 ft/min
Lowering }		20 ,,
Carriage travel in } two speeds	. . . .	100 ,,
Carriage travel out }		20 ,,
Long travel	. . . .	40 ,,

When tested the higher carriage-travel speed caused excessive swinging of the load and it was found possible to inch, on hoist or lower, without using the low speed The control was modified to cut out these speeds, and the simplified control pane has only eight buttons instead of the original twelve, which makes driving ver simple.

Ancillary to the mechanical equipment is a considerable range of lifting gea (slings, strops, can-hooks, timber dogs, etc.) and hand appliances (trucks, doomey etc.). To ensure uniformity of strength and quality at reasonable cost lifting gea should, so far as possible, be made up from British Standard components. Dealin briefly with chain gear, the quality of machine-made steel chain is superior to th hand-made wrought iron. Assuming that both the chainsmith and machine ca produce welds in wrought iron and steel as strong as the parent material, the chai will possess mechanical properties determined solely by the material from whic it is manufactured. The grades of chain in general manufacture are:—

B.S. 394:1951,wrought iron: breaking strain $27D^2$
B.S. 590:1949, mild steel: breaking strain $30D^2$
B.S. 1663:1950, higher-tensile steel: breaking strain $40D^2$

The property of wrought iron which has the most far-reaching consequences in th use of this material for chain gear is no doubt "work embrittlement," hence th periodic annealing. This is a phenomenon which is not encountered in steel and th need for periodic heat treatment no longer exists. On the other hand, the hea treatment of steel chain is an expert job and haphazard furnacing is a bad an dangerous practice. The simple fact that the blacksmith can no longer be regarde as a competent chain repairer is often quoted as an argument against the use of stee chain, particularly higher-tensile chain. There are, however, well-established firm of chain repairers, and it is also entirely practicable for large users to equip themselve satisfactorily for the work at reasonable cost. The availability of higher-qualit chain, whether used to increase safety factors or to reduce sizes, is an over-ridin argument in favour of the adoption of a policy of replacing wrought iron by stee Full use should be made of the quality of steel chain best suited to the specifi application under review, and a good lifting chain must possess the highest possibl ultimate tensile and yield points, compatible with the greatest energy and shoc absorption. The majority of cases fall into three categories, involving uniform wea differential wear, and stretch; reputable chain manufacturers are in the best positio to give sound advice on the most suitable type of steel.

With regard to hand appliances, a construction capable of withstanding heav usage is one involving a combination of steel and timber. The average annua maintenance cost of four hundred hand trucks of this type is £1 6*s* 0*d*, the averag purchase price being £9 0*s* 0*d* each. Figs 18, 19, and 20 illustrate some typica

vell-tried hand and lifting appliances. The trucks are fitted with hard-rubber-tired vheels with needle races. The extra cost of these wheels compared with the older ast-iron pattern is more than saved in reduced shed-floor wear and reduced operator atigue. The tubular-steel hand-truck, Fig. 21, is being used experimentally with a

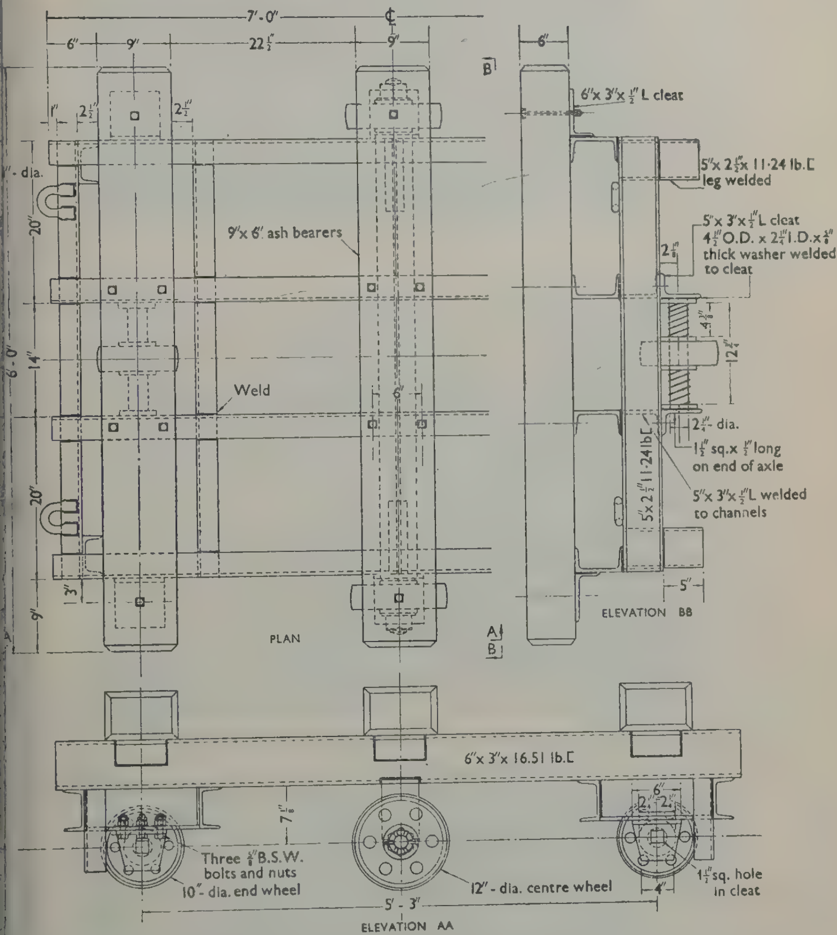


FIG. 18.—STANDARD FOUR-WHEELED DOOMEY TRUCK
(Capacity: 10 tons)

view to reducing maintenance. This truck costs £17 and weighs only 83 lb., compared with £14 16*s* 0*d* and 180 lb. for the equivalent standard timber and steel truck.

It is frequently necessary to discharge bulk cargoes by using dumping grabs on piece-work cranes. The Authority in this respect is concerned mainly with handling bulk sugar out of general cargo ships and uses 81/65-cu. ft twin-chain, coal-type grabs (Fig. 22) on 5-ton cranes. A grab has recently been designed specifically for ship-discharge work (Figs 23 and 24); it has a lower centre of gravity to prevent

tipping when dumped, heavy shrouding to obviate catching under coamings an damage to grab and ship, and wire-rope operation to facilitate block fall. This grab has been extensively tested and has given an improvement of about 25% in outpu per cubic foot of nominal capacity compared with the standard coal type.

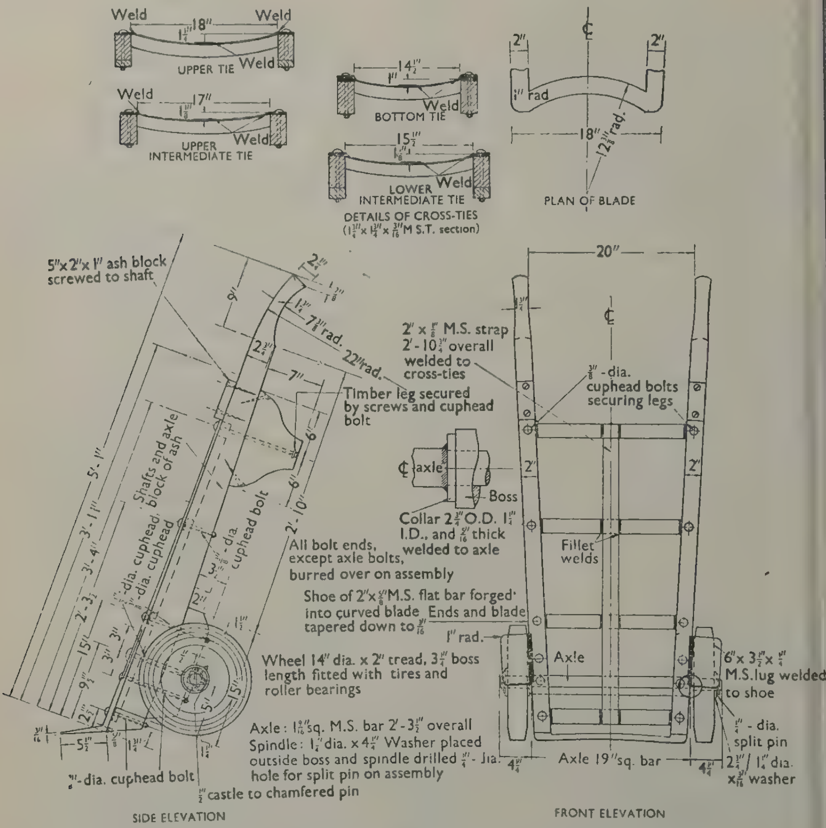


FIG. 19.—LARGE HAND TRUCK
(P.L.A. standard)

Unfortunately its dead-weight is greater than that of the coal-type grab, owing to the heavy shrouding and construction, and only a 70/56-cu. ft grab could be accommodated within the capacity of the cranes, which are limited to 4 tons when grabbing under B.S. 2452. About 17% of the Authority's costs for handling sugar, including overheads, results from ship, grab, and crane damages, and since output is only 45/50 tons per hour per crane, it was considered desirable to effect improvements, and in consultation with the manufacturers a new type of grab has been designed with aluminium buckets. As a result, the weight has been decreased by 6 cwt, and the nominal capacity increased to 81/65 cu. ft. It is anticipated that with this grab present output could be improved by at least 15 tons per hour and damage costs materially decreased.

Fig. 10.—Drum-type controllers installed in crank luffing quay crane

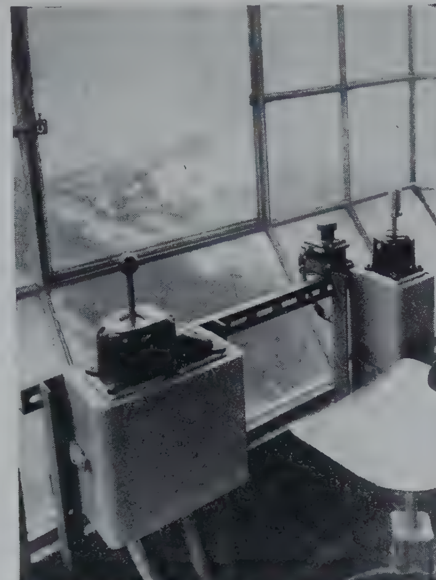


Fig. 11a.—Joystick controller installed in crank luffing quay crane

Fig. 11b.—Mock-up of bow-fronted cab and "joystick" controllers for crank luffing quay cranes

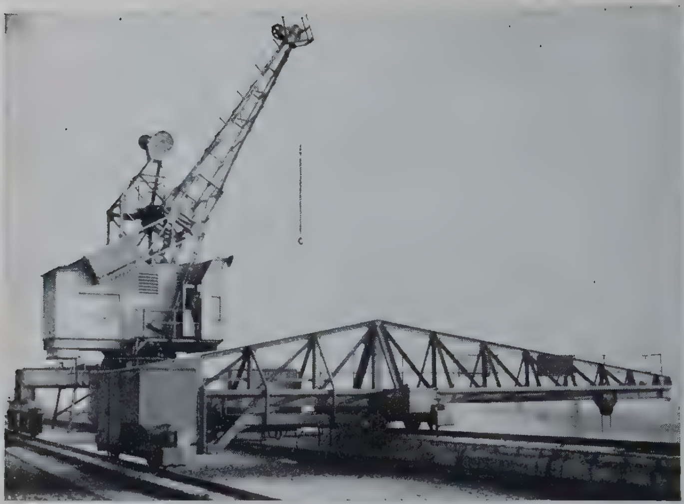


FIG. 16.—ROOF TRANSPORTER AND CRANK LUFFING ROOF CRANE

FIG. 17.—ROOF TRANSPORTER WITH PENDENT CONTROL PANEL AND CRANK LUFFING ROOF CRANE

FIG. 22.—TWIN-CHAIN COAL-TYPE 81/65-CU. FT DUMPING GRAB

FIG. 23.—PROTOTYPE WIRE-ROPE DUMPING GRAB FOR SHIP DISCHARGE: CAPACITY 45/36 CU. FT

Fig. 24.—Prototype wire-rope dumping grab for ship discharge (shown here dumping sugar)

Fig. 25.—Extension carriage and forks fitted to fluid-drive fork-lift truck for handling liner board

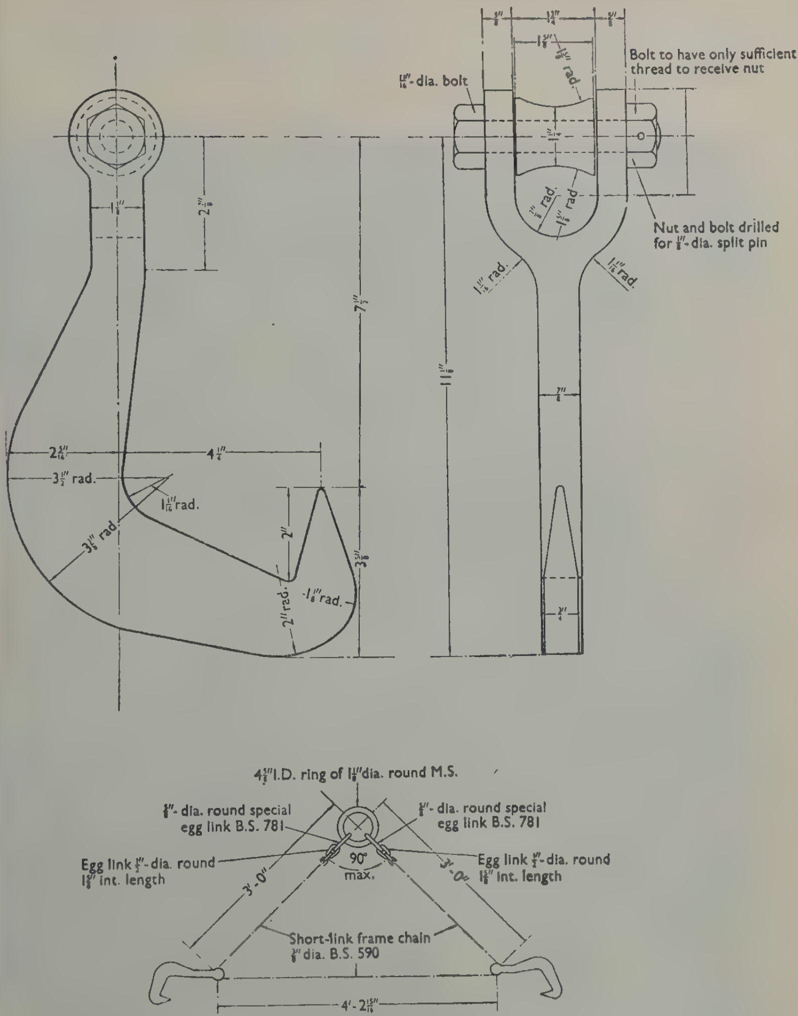


FIG. 20.—TIMBER DOGS
(Safe working load: 23 cwt)

The relative costs of the grabs are:—

81/65-cu. ft twin-chain coal type	£630
70/56-cu. ft wire-rope ship grab	£680
81/65-cu. ft wire-rope ship grab (with aluminium buckets)	£970

The Author is of the opinion that where piece-work cranes are likely to be used for more than occasional grabbing duties, they should be designed to the class 3 specification under B.S. 2452.

Where existing plant is of obsolete design but still serviceable it can frequently be modified to incorporate up-to-date equipment at a cost lower than that of replacing it. One instance is the conversion of non-luffing hydraulic wall cranes to electric by substituting a standard winch unit for the hydraulic hoist mechanism, slewing being

FIG. 21.—TUBULAR STEEL HAND-TRUCK. WEIGHT 83 LB. CARRYING CAPACITY 10 CWT

obtained by using an electric chain block (Fig. 26). The cost of the winch unit is £600 and of the slewing block £150. Including installation and erection the total expenditure for the conversion was about £1,400.

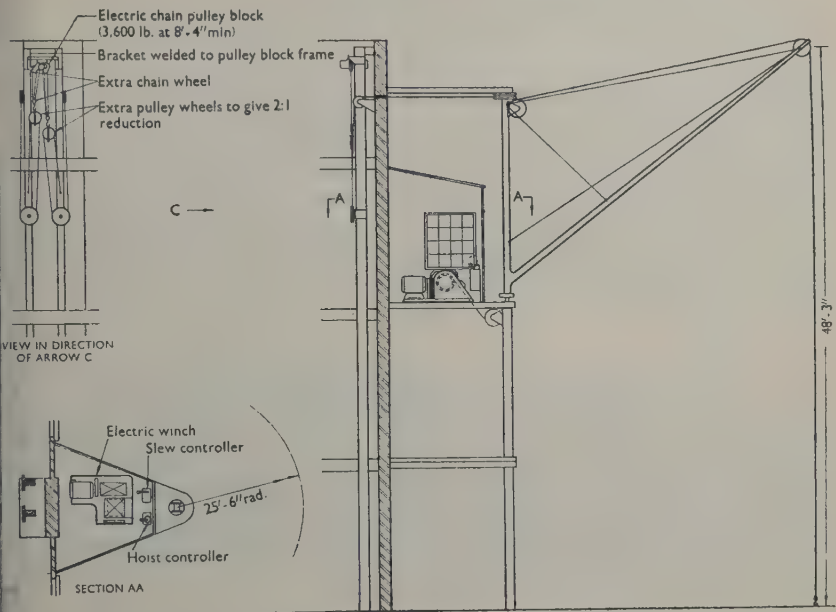


FIG. 26.—ELECTRIFICATION OF HYDRAULIC WALL CRANE

MAINTENANCE OF MOBILE EQUIPMENT

This section of the Paper is confined to the maintenance of the mobile cargo-handling equipment, and the scheme described is considered adequate for ensuring satisfactory availability of the plant at reasonable cost.

The Author considers that a wide knowledge is required to maintain all the types of mobile plant in use in a dock undertaking, and that the average craftsman's ability is better employed if he is required to operate only on these types of plant. It is therefore desirable that the maintenance of the mobile plant should, so far as practicable, be undertaken independently of the remainder of the dock work.

It is considered in general advantageous to use proprietary spares, rather than manufacture them in the dock workshops, and that specialized repairs (such as crankshaft grinding, cylinder boring, fuel-pump overhaul, etc.) are more economically undertaken by specialist contractors.

These considerations form the basis of the system to be outlined, which was drawn up to meet a specific requirement, but is considered to be generally applicable in principle. To formulate a satisfactory system it is necessary to deal with the problem under the headings, amount of plant to be maintained, frequency and type of repair, number and trade of the personnel required to execute the work, and layout of the workshops and their equipment; these form the basis for the scheme described.

Plant to be maintained

The plant to be maintained comprises the following items:—Fifty-five mobile cranes; thirty-six fork-lift trucks; thirty-four vehicles; sixteen tractors; eighteen

trailers; and numerous items of ancillary equipment. This plant is powered by one hundred diesel engines of fourteen types, and forty-five petrol engines of ten types.

Scheme of maintenance

The maintenance should be carried out systematically on a planned basis, to achieve high availability of plant which is kept in good condition.

In planning the maintenance system, no consideration need normally be given to major damage repairs since these have to be dealt with as and when they occur, and manpower and facilities have to be based on individual past experience.

The maintenance should be divided broadly into three stages, each of which is dealt with separately. These stages are (i) routine servicing; (ii) minor periodic overhauls of engines and attendant plant adjustments; and (iii) major engine and plant overhauls.

Routine servicing

It is considered that routine servicing is best carried out by a number of oilers and fitters based on areas corresponding to the day-to-day plant distribution. Schedules of items requiring daily, weekly, and monthly attention are drawn up. Each item of plant has its own service sheet on which is entered daily by the oiler or fitter, a record of any of the services he has carried out. The sheets should be checked periodically by the chargehand, returned to the office monthly for inspection by the engineer, and retained for 3 months. Where plant is undergoing minor periodic or major overhaul, the necessary routine servicing can be carried out by the men employed on this work who will enter up the sheets.

Minor periodic engine overhauls and attendant plant adjustments and repairs

In the case of diesel-engined plant, every 500 working hours the plant is withdrawn from service for a head overhaul of the engine, checking of injectors, fuel pump, etc., and a general check of the plant itself. Pro forma schedules are drawn up to cover the work and are filled in by the men doing the work and retained in the office until the major overhaul period occurs.

In the case of petrol-engined plant other than vehicles, work will be carried out after the same period of service hours.

In the case of vehicles, head overhauls and minor repairs need be carried out only as required and shown by routine servicing. It is not practicable to have a set programme since individual vehicles have vastly differing uses and running conditions.

Major engine and plant overhauls

In the case of diesel and petrol-engined plant other than vehicles, every 2,000 hours the plant is withdrawn from service for a complete engine overhaul and strip-down. Consequent on examination of the stripped plant, the extent of repairs is decided. No schedule of work to be carried out need be prepared, since a complete stripping is automatic, but repairs carried out must be recorded on the plant and engine history sheets.

Records

The following types of records, job cards, and schedules of work, etc., to be carried out at specified intervals should be kept. They will ensure an adequate amount of reliable information being available for each item of plant and eliminate much of the human error in deciding what work should actually be carried out.

Daily, weekly, and monthly service sheets for cranes, vehicles, tractors, and fork trucks.—To ensure that all necessary servicing is carried out and to maintain a running record of current work for periods of 3 months. Filled in by oiler and/or fitter concerned.

Plant history sheet.—To provide a record of repairs carried out throughout the life of the plant. Compiled by a clerk from service sheets and job cards, etc.

Engine history sheet.—To provide a permanent record of repairs throughout the life of the engine. Compiled by a clerk from service sheets, job cards, etc.

Tire history sheets.—To provide a complete history of tires during their life. Compiled by a clerk from service reports, etc.

Engine-hour wall chart.—Chart maintained showing the plant total hours since last

(*a*) head overhaul;
(*b*) major overhaul;
and (*c*) special information considered desirable;
(*d*) return of plant showing weekly hours worked.

Fitters job card.—Record of all work carried out by the fitters. Compiled by a clerk on instructions and data supplied by the chargehand. These are filed and any work can, at a future date, be traced back to the men who did it. On filing, job-card numbers can be entered in a book for cross reference, and also in a separate ledger if they are damage repairs.

TABLE 1

Operation	Men employed	Time required
Daily servicing of a mobile crane	Oiler Fitter Fitter's mate	35 min Average 10 min " "
Daily servicing of fork-lift truck (diesel) excluding battery charging	Oiler Fitter Fitter's mate Electrician	½ hour Average 10 min " " Nil
Daily service: vehicles	Oiler Electrician	5 min Nil
Daily service: tractors	Oiler Electrician	5 min Nil

Weekly servicing of cranes, fork-lift trucks, vehicles, and tractors, etc., by electricians:—

Vehicles Cranes Tractors Fork-lift trucks	Electrician	20 min

Weekly servicing of vehicles, tractors, etc., by fitters and mates only:—

On average about 10 min per vehicle and tractor once a week.

Manpower required for work of planned maintenance

Each item of plant requires attention at specific periods, i.e., daily, weekly, monthly, 2,000 hours, etc.

Each of the jobs takes a certain average time to do well. Table 1 shows a build-up of the total man-hours' work entailed in the planned maintenance scheme and from this the manpower required is deduced.

On one day a week, the weekly service is carried out. The time required on this day by the oilers would be double that needed for the daily service. These times are the result of a time study on a good oiler and are an average of three different types of cranes. Taking the total plant outlined on p. 267, gives in Table 2 total man-hours returned on the job for a six-day week.

TABLE 2.—TOTAL MAN-HOURS ON JOB

	Cranes	Fork truck	Vehicles	Tractors	Total
Oilers	224½	136½	19½	9½	390
Fitters	55	36	— — — 9 — — —		100
Electricians	— — —	Weekly total 48 hours — — —			48
Fitters' mates	55	36	— — — 9 — — —		100

Under present running conditions 500-hour engine overhauls fall due every 12 weeks.

The 500-hour head overhauls of cranes, fork-lift trucks, and tractors, on average entails the man-hours' work given in Table 3.

TABLE 3.—MAN-HOURS BEFORE OVERHAUL

		Fitter	Mate	Electrician
Crane	Engine	6	6	1
	Crane	4	4	
	Total	10	10	
Fork-lift truck	Engine	6	6	1
	Truck	3	3	
	Total	9	9	
Tractors	Engine	6	6	½ hour
	Tractors, etc.	2	2	
	Total	8	8	

With fifty-five cranes to head-overhaul every 12 weeks there is about one to do each day (Monday to Friday).

With thirty-six fork-lift trucks to overhaul there are two done about every 3 days (Monday to Friday), and with sixteen tractors about two every 3 weeks.

The weekly man-hours needed in the above are therefore: fitters, 88; mates, 88; electricians, 9.

Under present running conditions the 2,000-hour overhaul and complete stripping of the plant occurs every 48 weeks.

There will therefore be about one crane per week in hand, and two fork-lift trucks every 3 weeks, and one tractor every 3 weeks.

The average number of man-hours to overhaul these items are given approximately in Table 4.

TABLE 4.—MAN-HOURS TO OVERHAUL EQUIPMENT

		Fitter	Mate	Scaler	Painter	Electrician
Crane	Engine	35	35			6
	Crane	100	100	36	60	
Fork-lift truck	Engine	35	35			6
	Truck	50	50	10	20	
Tractor	Engine	35	35			4
	Tractor	8	8			

The man-hours per week involved are therefore: fitters, 206; mate (including scaler), 250; painter, 73; electrician, about 11.

The periodic semi-major and major overhaul of the vehicle fleet involve about the following weekly man-hours: fitters, 8; mate, 8; electrician, 12; painter, 26; scaler, 7.

The weekly total man-hours involved therefore is given in Table 5.

TABLE 5.—WEEKLY TOTAL MAN-HOURS

	Hours	Total
Oilers	390	390
Fitters	100 + 88 + 206 + 8	402
Mates (including scalers)	100 + 88 + 250 + 8 + 7	453
Electricians	48 + 9 + 11 + 12	80
Painter	73 + 26	99

The total manpower required for maintenance, servicing, minor, and major overhaul, excluding damages:

(a) based on a 54-hour week (or 10 hours overtime) and
(b) based on a 44-hour week (or no overtime) is:—

		(a)	(b)
Fitters	402	8	10
Mates	453	9	11
Electricians	80	2	The remainder of these men's working days during the 80 hours should be fully occupied on battery charging and damages
Painter	99	2	2
Oilers	390	7	8

Damage repairs

Incidence of damage is usually quite high and whilst some of it is heavy structural work beyond the scope of the mobile plant-repair organization, the amount of mechanical damage and minor structural work is often appreciable. It is not desirable to duplicate existing facilities for the heavy type of work; these should continue to be done by the main dock workshops.

From an analysis of damages, the following men were found to carry out the necessary repairs: two fitters, two mates, and no electricians (see above).

Total manpower for all purposes

The total manpower (actual work) required on a 54-hour basic working week is therefore: ten fitters. One of them could with advantage be replaced by a motor mechanic, for vehicle repairs. Eleven mates, two electricians, seven oilers, and two painters.

When the area to be traversed is large it is considered necessary to make a 10% allowance on the oilers', fitters', and mates' working day for time lost in travelling, locating plant, etc. The actual number of men required is therefore: eleven fitters, twelve mates, two electricians, eight oilers, and two painters.

Clerical and stores duties

With the above amount of plant and the requisite records to be maintained it is considered desirable to have a full-time clerk in the workshop. This man, apart from maintaining the records assists with the clerical side of the stores and generally does the clerical work entailed in the recording and reporting of damages for claims or managerial purposes.

It is unsatisfactory for the clerical work to be done by a labourer, since in no way can this type of work be considered the duty of such a man.

The ready-use stores are best dealt with by a storeman and no other staff is usually necessary. The total non-working non-supervisory staff required is therefore one clerk and one storeman.

Supervisory staff

The mobile plant in use comprised about 160 major units. Because of its rather complicated construction and because it is mobile, being powered by petrol and diesel engines, and because of its variety the plant requires a man of considerable knowledge and initiative to maintain peak performance with maximum operational availability.

Efficient planned maintenance will depend on each job being completed within the allotted period, and it is necessary to have a high standard of supervision if this is to be achieved.

It is therefore strongly recommended that the senior supervisor in these workshops, both because of the responsibility he carries and in order to make his rank more commensurate with the job, should be given staff grading of some standing. In addition there should be a chargehand fitter who would work at his tools, and supervise in the absence of the senior supervisor.

Workshop facilities required

The following items of plant would be in the workshop for maintenance at any time:—

	Cranes	Fork-lift trucks	Tractors, etc.	Vehicles
500-hour overhaul, say .	1	1	1	
2,000-hour overhaul .	1	1		
Periodic overhaul . .				1

or two cranes, two fork-lift trucks, one tractor, and one vehicle.

Apart from this machines in for damage repairs may be: one crane, one fork-lift truck, one vehicle or motor-cycle, and one tractor.

The total is therefore three cranes, three fork-lift trucks, two tractors, and two vehicles.

Fig. 27 illustrates the layout of the workshop which is considered adequate to deal with the maintenance of the plant listed together with a future increase of at least 25%.

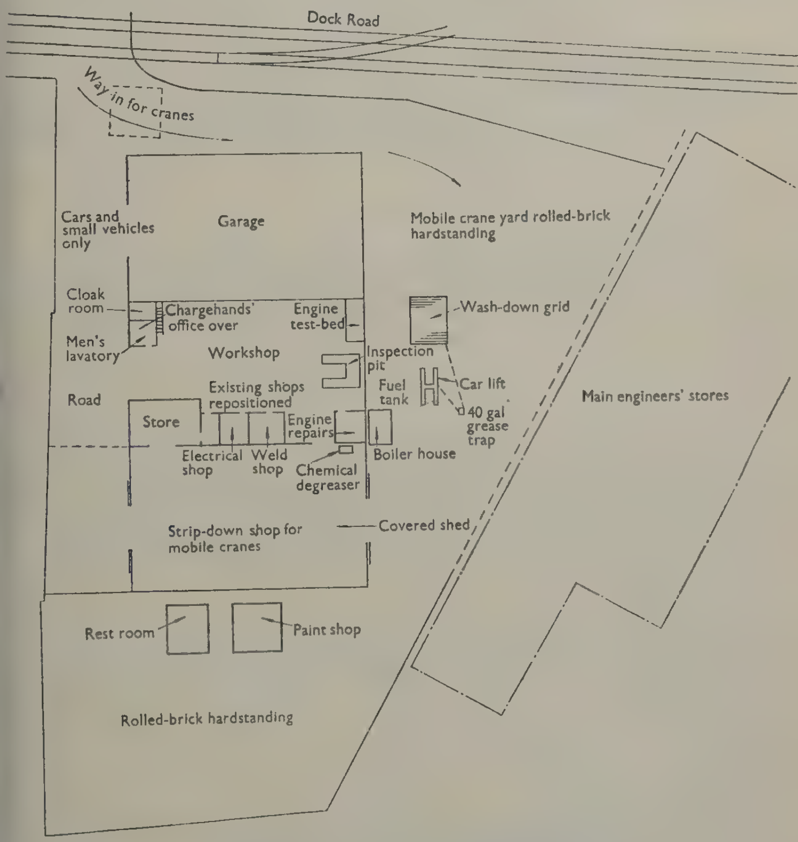


FIG. 27.—MOBILE-PLANT WORKSHOP

Buildings

It is considered that one building should be used only for crane repairs, and the other should house all the specialized bays and deal with the smaller plant in for repair (fork-lift trucks, vehicles, etc.).

The plant coming back for overhaul is often covered in dirt and grease. It should be hosed down and steam-detergent cleaned before it comes into the workshops, so that it is in a reasonable state of cleanliness before being stripped down.

Provision of heating, messroom, washing, and shower arrangements

The Author is firmly convinced that good working conditions are required for good work. Too frequently working conditions for maintenance men are so adverse that even good tradesmen are unable to give of their best. The most satisfactory heating system for workshops is one which provides a uniform temperature throughout the buildings. The messrooms should be of adequate size with suitable furnishings, which are both bright and durable; drying and cooking facilities are very desirable. In addition to washing arrangements, it has been found that shower baths are an amenity appreciated by most men, once they have overcome the novelty of the idea.

Provision of rolled-brick hardstanding

In order to give a workmanlike and presentable appearance the surrounding area can be finished in rolled brick. Circulating access to the buildings is thus provided at low cost, together with hardstanding for plant coming in for repair or awaiting return to work.

Transport and equipment required

Adequate transport is a necessity when a large area is covered, if repairs and breakdowns are to be dealt with expeditiously. A Jen tug with two trailers and a van have been found to be adequate to deal with servicing and repairs carried out to plant in situ.

Equipment required

(1) Chemical degreaser, of adequate size to degrease a complete engine and larger crane parts.
(2) Weaver compact "H" model steam-detergent degreaser for cleaning plant down before it enters the workshops.
(3) Adequate benches and adjacent racks for holding stripped components.
(4) Battery chargers.
(5) Compressor.
(6) Vehicle lift.
(7) Tire vulcanizer.
(8) High-pressure water-cleaning equipment.
(9) Engine stands.
(10) Pedestal drills.
(11) Jacks.
(12) Valve and seat grinders.
(13) Portable hand grinder.
(14) Adequate hand and power tools for this type of work, portable low-voltage light, and air-line connexions.
(15) Pressure-greasing and oil-dispensing equipment.

Major items of spare gear to be held

In order to expedite maintenance and breakdown repairs the following are considered necessary, in addition to the normal holding of spares:—

Complete diesel engines: one for each twelve engines of similar types.
Spare wheels, complete with tires: one for each type of plant.
Spare cylinder heads complete with valves: one or two for each type of engine.

Use of specialist contractors' services for engine repairs

It has been stated that specialist work should be undertaken by contractors. Apart from crankshaft grinding, boring, etc., most engine manufacturers have a replacement engine scheme, which in certain cases it is economic to use. The approximate cost of contractors' services are listed below, and each case arising will need to be treated on its merits.

Cylinder boring 3 to 4 in. dia., £1 2*s* 0*d* per bore.
Crankshaft grinding small engines, £2 0*s* 0*d* per pin.
Main bearing remetalling and line boring, £15 0*s* 0*d* for a 4-cylinder engine.

Replacement reconditioned engines cost as follows:—

Perkins P.4.	£120	approximately
Perkins P.6.	£140	,,
Ruston 2 VTH	£93	,,
Ruston 2 VSH	£125	,,

Plant availability

Shortly after the introduction of the foregoing scheme, the plant availability was:—

Mobile cranes	90%
Fork-lift trucks	88%
Tractors	95%
Vehicles	98%

When the scheme has been fully in operation for some time it is anticipated that the crane and fork truck availability will be improved to 92 to 95%.

ACKNOWLEDGEMENTS

The Author is indebted to the Port of London Authority for permission to use the information contained in this Paper and is grateful to the Chief Engineer, Mr G. A. Wilson, M.Eng., M.I.C.E., M.I.MechE., and to his colleagues who assisted in its preparation.

The Paper, which was received on the 6th December, 1955, is accompanied by ten photographs and nine sheets of diagrams from which the half-tone page plates and the Figures in the text have been prepared.

Maritime Paper No. 35

HANDLING OF PORT TRAFFIC

by

*** Ernest Stanley Tooth**

SYNOPSIS

This subject is particularly interesting at the present time because a revolution in cargo handling methods is taking place. The main impetus to this revolution arises from the world-wide need to turn ships round quickly. Shipping interests are much concerned with the proportion of their outlay spent on ships in port.

Speedy loading and discharge involve the need for speedy handling of goods into and out of port premises. Transit sheds particularly must always be cleared as quickly as possible. Thus, shed appliances must be as efficient as quay cranes and ships' purchases.

The two most important appliances which are eliminating delays on the quay are the mobile crane and the fork-lift truck. To operate these machines speedily and safely, drivers must be keenly aware of certain principles new to port operating work. The employment of these appliances makes for speedier working, saves space, reduces arduous labour, and often lessens pilferage and breakage risks. It also involves, however, alterations in layout and design of quays, transit sheds, and warehouses.

Many of the benefits mentioned could not have accrued without the introduction of dock pallets and the method employed at modern mechanized berths often revolves round the employment of these tools. This way of working is closely related to the unit-load method of transporting goods, which is expected ultimately to become universal. Goods would then travel as unit loads from production line or shippers' premises to foreign destination without need arising at any time for individual packages to be man-handled. When this development occurs, ports modernized in the way described below will find no difficulty in handling the new-type traffic.

General methods of mechanical handling

As, in the interests of speed and economy, port-operating work is becoming more and more mechanized, the task confronting those responsible for it becomes increasingly complex. Further developments in mechanization are inevitable. It is more important than ever before, therefore, that there shall be the closest co-operation between responsible port-operating officials and their engineering opposite numbers.

Since 1945 one of the most important needs has been to turn ships round quickly. Prior to the 1939–45 war, shipowners spent about 40% of their outlay on ships in port. For various reasons, many of them connected with labour, this figure has increased and is now calculated to be nearer 60%, and not only shipping interests but very often governments are much concerned about it.

In Britain one of the most important factors affecting cargo-handling methods is that both import and export cargoes are so miscellaneous. There are berths which deal with vessels of different lines, bringing a huge variety of goods; there are others catering mainly for ships of the same line or ships engaged in a regular traffic. Even regular traffic may consist of many different types of cargo and the consignments in

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* The Author is an Administrative Officer of the Port of London Authority.

one vessel can include bales of rubber, chests of tea, bags of rice, pieces of lumber, bundles of canes, military stores, hardwood logs, bags of cotton seed, cases of canned pineapples, and bales of coir fibre and hemp. Stevedoring agents must always be prepared not only to handle such mixed cargoes speedily but also to cope with new packs and new commodities at short notice. Bearing in mind, too, that ships vary a great deal in size and construction, it will be appreciated that the gear and equipment required for port-operating work must be of widely varying types and capacities, and the handling machines must be at least versatile.

The port appliances which first handle imported goods illustrate the latter point. At a modern berth, the quay cranes used for general cargo, i.e., for piece goods, will be speedy on all motions, level luffing, transportable, and self-propelling. In radius and capacity there will be big variations. A radius of 80 to 100 ft will be necessary, for instance, if there is need to plumb across ships of wide beam or to discharge cargo from vessels berthed against a pontoon to allow barges to be loaded between ship and quay. A long jib will be necessary if it is required to lift goods to a high storey of shore premises. The operator, however, normally prefers the shortest possible jib satisfactory for the work in hand, because he can then see and control his load better. A package swinging on the end of a 100-ft bond cannot very easily be deposited speedily and safely at a certain spot or in a conveyance. So far as lifting capacity is concerned this, too, will depend upon the type of traffic the crane is expected to handle and will, of course, be controlled by the heaviest probable load.

Consideration of methods of handling goods on quay and in transit sheds leads inevitably to the question of the design of port premises; this will be dealt with more fully later. For the time being it is sufficient to say that modern quays, transit sheds, and warehouses must be suitable for the new-type machines which are revolutionizing cargo handling throughout the world. The particular appliances in mind are the mobile crane and the fork-lift truck; although straddle carriers, platform trucks, pallet trucks, tractors and trailers, conveyors, stillage, and hand trucks all form part of port-operating equipment, none has the general importance of the mobile crane or the fascinating possibilities of the fork-lift truck.

Mobile cranes

The mobile crane handling cargo from shed to vehicle and *vice versa* must, like the quay crane, be to some extent a general-purpose machine, since, as stated, British imports and exports are normally heterogeneous. Some jobs, however, may demand a crane which is to some degree specialized. Handling heavy logs, for example, requires an appliance with a good out-reach so that the load is unlikely to damage the crane structure. Working under a canopy may require a crane specially designed to reduce the maximum jib height without lessening out-reach.

In the main, however, the operating factors controlling the design of the mobile crane are the same as for the quay crane. The need for a high speed of operation is obvious, for without it receiving from ship will be slowed, deliveries from shed delayed, and the berth will become congested. In addition, the machine must be easy and safe to drive, it must be manœuvrable, and it must be reliable. Its maximum lifting capacity may range between 10 cwt and 10 tons or more, depending upon local requirements. Its jib length varies similarly—normally between 10 and, say, 40 ft. Since operators prefer a compact machine, a crane selected for a particular type of work will not usually have much spare out-reach.

On the question of safety, much attention is necessary to stability. Since (in contrast to the quay crane) the safe working load of the mobile crane varies with the

angle of the jib, the driver must exercise much care and always bear in mind that once a package is picked up within the maximum radius of the crane, the jib must not be luffed down beyond the safe position shown on the safe-load indicator. Swinging a load during the slewing operation, working the crane on a sloping surface and even having tires of uneven pressure all tend to cause instability and it is necessary from the operating point of view that the safety margin allowed takes these matters into account.

Manœuvrability has been mentioned. Particularly on congested berths good manœuvrability is essential. It can be obtained in more ways than one, e.g., by constructing the crane so that the whole superstructure will slew with the jib round the full circle, or by designing the whole crane to slew, usually by means of the castor action of one or other of the axles. Sometimes there is an operating reason for preferring one method to another.

Manœuvrability requires also the smallest tail-radius consistent with stability, and it is important, too, to ensure that the type of tires fitted to the crane wheels is suitable for the surfaces upon which the machine normally has to work.

How cranes should be powered and whether some should be rail-mounted are also questions which may have different answers at different ports or even at different quays. Petrol-powered machines are sometimes accompanied by a fire risk; diesel-powered machines (either diesel or diesel-electric), like petrol machines, sometimes create difficulty with exhaust fumes when working in confined spaces; steam cranes, which are often rail-mounted (as indeed are diesel cranes) incur stoking costs which are sometimes heavy; electric-mains cranes are not completely mobile; battery-powered machines may slow down or even stop working towards the end of a busy period. Speaking very generally, most port-operating officials may prefer diesel-electric machines on grounds of reliability. They may also be smoother to drive. Very often, however, running costs are the deciding factor.

One last point on mobile cranes is that consideration has to be given to the fact that in the major ports of the United Kingdom most gangs are employed on piece-work conditions. As already stated, it is the employer's aim to attain the maximum working speed consistent with safety. A high working speed is also normally the aim of the piecework gang; this is obviously an additional reason why, in designing the mobile crane, careful attention must be given to the margin of safety. It is another reason why cranes for port work must be robust.

Fork-lift trucks

The introduction of the mobile crane into port-operating work was simplicity itself compared with that of the fork-lift truck, mainly because the former usually displaces little labour. The fork-lift truck called attention to itself because it was so versatile and, when first introduced, was regarded as the panacea for all industrial ills. Although that opinion was quickly proved to be false, there is no doubt that this appliance is becoming invaluable to port operations. At present it is, in fact, the most commonly used handling device. It is employed to lift, convey, stack, turn, invert, and rotate loads and even to pour from containers; although gripping devices have reduced the need for pallets, the introduction of the machine has done much to make port authorities, shipping companies, stevedores, and others pallet conscious.

In the United Kingdom the fork-lift truck was introduced into dock and harbour work on an empirical basis. Employers felt that it would be extremely useful but were not certain in what way, particularly since there was much doubt as to the workpeople's attitude to it. One development in goods handling which was

expected was the employment of the "throughout movement method." Had this occurred, it would have *demanded* the introduction of the fork-lift truck. This method is, of course, the consigning of cargo as unit loads instead of as individual packages. It usually involves the palletizing of goods at production or shipper's premises, so that they can travel as unit loads right through to foreign destination. Port authorities and others, by introducing the fork-lift truck and becoming familiar with its use, were prepared to deal with such traffic. In point of fact, however, except in certain short-sea trades, this method has not yet developed at all.

What has developed is the use of the fork-lift truck with pallets owned by the dock-labour employer and which never leave the berth. These pallets (Fig. 28) are, in fact, dock tools and the latest type has a metal eye at each corner so that it can be lifted aboard by quay crane or ship's derrick as well as conveyed by fork-lift truck.

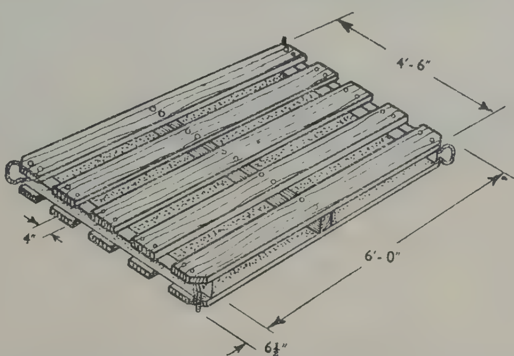

FIG. 28.—THE STEVEDORES' PALLET—A DOCK TOOL

There is now hardly need to state that a primary reason for introducing the fork-lift truck into port-operating work was to increase working speeds, and since, at the mechanized berths, goods are handled in unit loads of upwards of 1 ton, conveying, piling, warehousing, and delivery are performed much more quickly than by the manual package-by-package method. In fact, where the truck can operate without hindrance, speeds of handling cargo to and from ship and also on quay and in transit shed have often increased by between 20% and 40% dead-weight tonnage.

There are, however, other benefits besides speedy working which accrue from the use of the fork-lift truck. For instance, since a standard truck (12-ft lift) can pile palletized goods up to, say, 16 ft high, shed capacity is often doubled, despite the need to leave wide working gangways for the machine. At ports where transit-shed space is at a premium, this additional accommodation is a boon. Another benefit is that palletized goods are subject to less damage and less pilferage. This is obvious when it is considered that at a manual export berth each package may have to be man-handled as many as five times between receipt and stowing in hold, whereas at a mechanized berth, the only man-handling is from vehicle to pallet (at shed door) and from pallet to stowage (in ship's hold). The conveying to shed, the piling (Fig. 29), the subsequent unpiling (Fig. 30), and conveying to ship's side are all done by fork-lift truck at the mechanized berth and there is no need, of course, for the goods to be handled into ship's slings for lifting aboard. They remain on the pallet (Fig. 31).

The operating requirements of the fork-lift truck are therefore similar to those needed in the other machines mentioned. The appliance must be speedy in travel in lifting, and lowering; it must be stable, manœuvrable, reliable, and easy to drive. Operating officials usually want the biggest speeds and lifting capacity without having a clumsy machine. For general work it is certainly necessary to have a 12-ft lift, a capacity of 2 tons or more (at 24 in. or 27 in. from fork heels), a travelling speed of 8/9 m.p.h., and a lifting speed of, say 40/50 ft/min. The margin of safety must be a fair one, not only because the goods which pass through ports sometimes have their centres of gravity in unexpected places but also because slopes and uneven ground affect the stability of the machine, particularly when it is loaded. In a factory dealing with packages of standard sizes and weights on level floors, this aspect can be viewed differently, particularly if there is no piecework complication.

Types and sizes of pallets are more varied than those of the machines which carry them. One very important matter from the point of view of shipping interests, however, is that pallets should be big and strong enough to carry an economic load for quay crane or ship's purchase. Hence most "dock-tool" pallets are 48 in./54 in. wide and 64 in./72 in. long and many have a carrying capacity exceeding 3 tons and a stacking capacity of more than 6 tons. The very important question of pallet sizes, however, is at present being dealt with by a technical committee of the International Organisation for Standardisation and it is hoped that when this committee has finished its work and pallets for international trading have been limited to certain sizes, the "throughout movement method" will at last begin to develop between continent and continent. If that occurs, not only will there be fewer types of handling machines required but the variety of types of "slinging" gear should also be substantially reduced.

At the present time hooks, clamps, nets, skips, landing boards, and platforms and many types of rope, chain and wire snorters and slings are in common use with quay, mobile, and other cranes. Unit-load traffic, irrespective of the commodity on the pallets, would all be "slung" by a limited number of types of gear such as a bar-sling, which would fit safely in the pallet wings, or spring-loaded crane forks, which would penetrate between the pallet decks. Whatever the future holds in this sphere, interesting developments are certain.

There are, of course, some cargoes which could not or would not be palletized even in a port where the most advanced methods so far envisaged were employed. Typical examples are bulk sugar, a staple British import, and motor-cars on wheels, one of Britain's most important exports. Cargoes of this kind require special handling equipment, although not necessarily special cranes.

Handling of sugar

After a great deal of experiment, including the use of suction plant, it has been confirmed that the best means of discharging bulk sugar is by grabs. Although grabbing cranes are preferred, at ports where bulk work is intermittent discharge is often done with ring-discharge or self-dumping grabs on piece cranes. The largest piece cranes likely to be found on berths allocated to general cargo vessels have a lifting capacity of 5 tons. By employing such cranes with suitable self-dumping grabs, outputs of 500 tons per gang per 8-hour day are obtained, at least while there is a good bulk of sugar in the square of the hatch. To maintain high outputs, however, mechanical trimmers are necessary in the ship's holds and for this purpose a bucket loader with a capacity of 6 to 8 cwt of sugar per lift has been found to be suitable. This is employed mainly on the ceiling of the ship; in the 'tween-decks, light bull-

Fig. 29.—Conveying and piling palletized exports in transit shed
(*Photo: P.L.A.*)

Fig. 30.—Conveying palletized exports from transit shed to ship's side
(*Photo: P.L.A.*)

FIG. 31.—LOADED STEVEDORES' PALLET BEING LIFTED ABOARD EXPORT VESSEL

Photo: P.L.A.)

FIG. 32.—TWO MODERN BERTHS CONSTRUCTED BY THE PORT OF LONDON AUTHORITY AT WEST INDIA DOCK

(*Photo: P.L.A.*)

FIG. 33.—SOME OF THE CRANES AT THE NEW BERTHS
(*Photo: P.L.A.*)

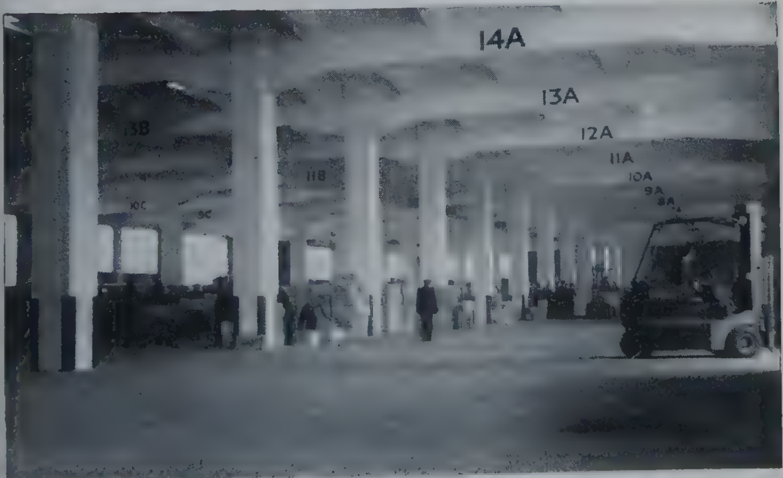

FIG. 34.—GROUND FLOOR OF THE SHED AT ONE BERTH
(*Photo: P.L.A.*)

FIG. 35.—BALCONIES AND ROOF CRANES AT THE REAR OF THE SHEDS
(*Photo: P.L.A.*)

FIG. 36.—RAIL TRACKS AND ROADWAY AT THE REAR OF THE SHEDS
(*Photo: P.L.A.*)

ozers or angle dozers are often used, when the method is to push the sugar into the quare of the lower hold, thereby supplementing the work of the bucket loaders.

With this commodity speed of handling is also of vital importance, because the ver-riding factor is always to make the ship's stay in port as short as possible. Hence steps are usually taken to enable discharge to proceed on both sides of the essel simultaneously. Thus, at a quay berth the ship is moored against a pontoon, o that barges may be loaded between ship and quay as well as on the side away from he quay. For work proceeding on that side of the vessel, another special device is ften employed. This is a hopper fitted with a spring mattress (for self-dumping rab) and two long outlets. This appliance is placed on the deck on the "outside" f the ship and all the crane has to do is to lift the loaded grab from the hold and ower it on to the mattress of the hopper. This halves the distance of the luffing notion, it obviates slewing, and the crane driver can work more quickly because, for nost of the operation, he does not have to rely upon another man's signals.

Handling motor-cars

Motor-cars on wheels sent to port for export do not require any special handling machines but they do require special lifting gear. They are usually driven to the berth or are brought on special carriers, from which they are run to ground level. When a car is required alongside the ship, it is often towed from the parking ground by a fork-lift truck, which finally pulls it over the motor-car lifting gear, which has been placed in readiness on the quay alongside the hatch concerned. Gear of this kind often consists either of a pair of oblong nets or of a pair of sets of slats which, when tightened by lifting, takes the weight of the car on the treads of the wheels. Some stevedores prefer a type of gear which consists of four metal wheel scissor-grips. Whatever equipment is used, however, the rope or wire legs supporting it are held away from the car body by means of spreaders.

Even for car-handling, however, the fork-lift truck has been employed as a piling machine. At one European port, where parking space is scarce, tubular scaffolding "shelves" have been erected and experiments made with a 16,000-lb. fork-lift truck, fitted with very long forks, which placed cars three high, each car resting on its own shelf. There is no doubt that the versatility of the fork-lift truck has not yet been fully exploited.

The design of premises

It will now be appropriate to examine how the introduction of new cargo-handling methods is affecting the design of port premises. For a very long time it was the practice to construct one transit shed per berth and as ships increased in size sheds also became larger. However, whilst most jobs were done manually, perhaps with the use of two and four-wheeled trucks, or were at most mechanized by the employment of conveyors or powered platform trucks, little alteration was necessary in shed design.

After the second world war the position changed. The need to use mobile cranes and fork-lift trucks with dock pallets has called for a new overall approach and berths are now being constructed on a new pattern. Primarily they must have ample working space for the machines, not only inside the shed but also outside. This is provided by adequate cart areas and approach roads, wide quays, wide and high doorways and also, inside the shed, the minimum number of supporting columns, with plenty of room to work upwards. All working surfaces are smooth, level, and

hard-wearing and the shed has good natural and artificial lighting. This is importa since goods have to be piled high and meticulously.

Two berths embodying these principles have recently been built by the Port London Authority at their West India Dock to accommodate ocean-going vesse up to 500 ft or more in length (Fig. 32). The quay is 50 ft wide and is equipped wi two sets of standard-gauge rail tracks and with 3-ton portal quay cranes of t crank-operated level-luffing type, electrically driven on all motions, includi travelling. Each shed consists of three storeys, ground and first floors being trans accommodation, the top floor providing about 4,000 tons of warehousing space. (the quay side, the first and second floors are each set back 15 ft leaving wide veranda which can be plumbed by the 65-ft and 80-ft-radius quay cranes (Fig. 33). T ground floor measures 432 ft × 128 ft × 24 ft 6 in. high. Doorways are 22 wide × 20 ft high. The height of each of the upper floors is 16 ft 6 in.

The smooth hardwearing floors (Fig. 34) of reinforced concrete have prove satisfactory for mobile cranes and fork-lift trucks. Fork trucks of 3-tons capaci work on all floors; on the top floor they pile, among other goods, reels of liner boa weighing up to 4,500 lb. each.

At the rear of the shed the staggered balconies (Fig. 35) are large enough for ea negotiating by loaded fork-lift truck. These balconies, the ground-floor doorway and the rail tracks alongside (Fig. 36), are served by travelling roof cranes of 30-cw capacity (Fig. 35). The spacious cart area between the sheds has proved invaluab It is 230 ft long and extends about 200 ft back from the quay edge. Appropria attention has also been paid to lighting and there is no doubt that the shed desi is not only completely satisfactory now but that it is likely to remain so at lea until even more revolutionary handling machinery is invented.

It may be useful to conclude by following some hypothetical consignments imports from quay into and then out of the transit shed at a mechanized bert The cargo (except bagged goods) will probably be lifted ashore on the large pallc already described. These loaded pallets will be picked up from the quay at the shi side by fork-lift truck and taken into the transit shed either to piling ground or sorting pitch. The goods for direct piling will be stacked by the conveying tru but mixed pallet loads will be sorted elsewhere on to fresh pallets for subseque piling. Since valuable, pilferable, and bonded goods often have to be placed "lock-up" accommodation these "cages," too, are constructed to allow access by t new machines.

Some goods, e.g., large casks, battened cases, and reels of paper can be handled l fork-lift truck without the use of pallets. Others—particularly bagged goods—a handled in rope slings. Sling-loads are conveyed into the shed by platform tru and then lifted to pile (sometimes twenty-five bags or more high) by mobile cra or belt-conveyor.

Since, as already stated, the transit shed must be cleared without delay to ma room for the cargo from the next ship, goods not for immediate delivery have to l warehoused. Whatever operation is required, however, it will normally be perform by one of the machines mentioned. The bags will be conveyed by platform tru (if the vehicle cannot get alongside the pile), the unit loads by fork truck. Th machine will place a load on the tail-board of a lorry or the floor of a railway wag and go about other work while the goods are being stowed from pallet to vehic The fork-lift truck will also deliver the pallet load under plumb of a mobile, qua wall, or roof crane for delivery to barge or into warehouse. At all interim handlin these goods remain in unit-load form; only when they are finally passing out of t

ustody of the port organization are the loads broken down and the packages handled eparately. Even that is not always necessary, however, for at isolated places the ractice has already begun for dock-owned pallets to go to consignee for unloading.

Future trends

It is true to say, of course, that the mechanized methods described are so far eing fully employed only at certain pioneer berths. Nevertheless, the modern rend is now clear. For piece goods, it is unit-load handling instead of individual ackage handling—to effect savings in time, space, money, and arduous labour. he evolution of this method is already far enough advanced to affect not only the ypes of port equipment required and the layout of quays, sheds, and warehouses ut also, in the general industrial world, goods-packaging, transport-vehicle design, nd the pattern of factory and other premises. There is little doubt that it will ltimately affect ship construction.

In maritime countries, speed of ship discharging and loading, with care of cargo nd safety of personnel, is essential to the national economy and, although existing inds of equipment are being improved daily, it is from the new-type appliances that he more dramatic benefits are expected. When these accrue, the recipients will ot only be the port employers and the shipping companies, they will include manu-acturers, shippers, receivers, haulage and lighterage contractors, many groups of ork-people and, it is hoped, the consumer.

The Paper, which was received on the 18th October, 1955, is accompanied by eight hotographs and one drawing from which the half-tone page plates and the Figure n the text have been prepared.

Discussion

Mr J. H. Jellett (Docks Engineer, Southampton, British Transport Commission) aid that he had been encouraged to hear Mr Lees advocate close co-operation between hipbuilder and port-owning authority in the planning stage of design of new ships. He hought he could say that certainly so far as Mr Lees's own company was concerned—who appened to be Southampton's biggest customers—there was very close co-operation in ll planning arrangements, both ship and shore. But he did not think that the same held ood for all Mr Lees's colleagues in other shipping lines in Britain and overseas. An xtreme case was the *United States* when she came to Southampton on her maiden voyage nd there had been the problem of unloading the baggage. The range of the problem was ide because it involved taking baggage off decks 30 and 35 ft above the quay level and aking personnel out of decks 6 or 7 ft below quay level. A number of inventions and nusual appliances were devised to cope with the problem.

Turning to Mr Matheson's Paper, he wished to make a few comments on the age-old roblem of columns. Mr Matheson had stated that he felt that a 30-ft spacing should be dequate for all purposes and suggested on p. 253 that there was perhaps a tendency for ngineers to exhibit advances in technical skill. The temptation for the engineer to seize uch an opportunity was undoubtedly very great. At Southampton there had recently een completed a two-storey transit shed in which the column spacing had been opened ut to 54 ft $\times$ 49 ft. Since the calculated loading on the upper floor was 3 cwt/sq. ft, the upporting structure of the upper floor was very massive. The load down some of the nternal columns was as much as 800 to 820 tons. Many people might say that the

engineers had been extravagant, but they had offered the problem to the managemen very clearly, opening the spacing of the columns out gradually from a basic economi spacing of about 22 ft 6 in. in both directions stage by stage, with the appropriate additiona cost at each stage; when the figure finally approved was reached, that was then selecte The management had been told what the additional cost of such an exhibition of technica competence would be. The building had been greatly admired from the operating poin of view because of the marked lack of obstruction from columns on both floors. Th total floor area of the two floors was about 170,000 sq. ft; since the building had bee opened six ships of Mr Lees's line had been accepted, i.e., one ship per week, and an averag of nearly 9,000 measurement tons of cargo had been unloaded per week.

Another point mentioned by Mr Matheson was that the slope of the floor should no exceed 1 in 100. It had always been the practice at Southampton to slope the shed floor up from quay level on the waterside to the standard rail platform level at the other side o the width of the shed. That meant that there was a rise of about 3 ft 6 in. to be achieve in a width which might be as little as 120 ft or perhaps even narrower, so that the steepes floor was 1 in 28. He realized that that did throw a considerable load on the battery operated trucks which carried most of the cargo moved on the floors of those sheds, bu so far as he was aware that had never resulted in trucks going out of action before a shif was over.

Finally, he felt that an economic case had not yet been made out for shed doorway sufficiently high to take mobile cranes with their jibs hoisted. A crane was a liftin device, and it should not be made to function much as a moving device. It was not th structural design of the doorway that caused trouble, but the subsequent maintenanc of the very large and unwieldy doors necessary to close the openings.

Mr P. R. Robinson (Messrs Rendel, Palmer & Tritton, Consulting Engineers) sai that he wished to speak on the layout of transit areas, particularly from the point of view of imports, because very often they chiefly affected the amount of transit area to b provided.

Such areas, whether whole sheds, floors of sheds, or open dumps, should be used fo transit purposes only. In some ports there had been a considerable tendency during th past 10 years for goods to remain in transit sheds and dumps far too long, and some por authorities had found it difficult to insist on prompt removal by importers. Generall speaking, there should be no need for imported goods to remain in transit areas more tha 5 days, but under present circumstances perhaps 10 days should be allowed.

The transit area should thus be able to accommodate the volume of goods unloade from a ship in that time if they were cleared at the same rate as they were unloade Taking an average of the figures given by Mr Matheson of from 120 tons to more tha 300 tons of cargo per foot of berth per annum and allowing 250 working days a year fo a 600-ft berth, one got a figure of, say, 600 tons per ship per day. Now, assuming tha goods did remain 10 days in transit areas, transit accommodation would therefore have t be provided for at least 6,000 tons. Therefore, every extra day beyond the 10 day assumed of retention in transit areas increased the transit space required by 10%. I was often difficult to provide sufficient conveniently arranged transit accommodation t allow for normal periods for goods in transit; it was therefore important that every effor should be made to reduce the time goods remained in transit areas to the minimum possibly by a sliding scale of fees. An investigation by a special committee of the Liverpoo Steamship Owners' Association into congestion and slow discharge had found that th over-riding cause was congestion on the quays through failure by receivers to clear good in proper time (quoted in "The Times" of 19 March, 1956).

Taking Mr Lees's figure of 50 cu. ft/ton, the net volume occupied by 6,000 tons of carg was 300,000 cu. ft. If it was stacked to an average height of 8 ft, which was perhaps hig for general cargo even with pallets and certainly high for many ports abroad—especiall where individual consignments were not large—the net area occupied was, say, 35,000 t 40,000 sq. ft. But since up to 40% or more of the gross area was devoted to alley-ways lifts, and so on, the gross transit area required for 6,000 tons of cargo was actually more lik

0,000 to 70,000 sq. ft; that did not include roads, railways, and loading platforms, nor id it allow for export cargo which might have to be stacked for loading into the same ship r the next one. Thus, the total gross transit area required for a 600-ft berth was likely o be at least 100,000 sq. ft. If the width of the transit area was taken as 150 ft, that area ould not be provided behind a 600-ft berth using single-storey transit sheds.

He did not like the awkward shape of transit shed shown in Fig. 2, Plate 3. If, however, ail access to the apron from the standage grids at every berth was essential, some such rrangement was almost inevitable, unless a very short multi-storey shed was used, ecause normally there was just not enough room between transit sheds to get in the rail urves of the necessary radius. He thought that rail access from the rear at each berth vas unnecessary, and it was usually quite sufficient to have turn-outs at every third or ven fourth berth. The rail movements on the running line on the apron in such cases vould not need to be so frequent as to interfere much with goods passing between ship and ransit shed on adjacent berths.

There were at least two other reasons why the cut-off corner of the transit sheds was bjectionable. The triangular section of a shed was awkward to manage for stacking urposes, and that end could not be used for road clearance or at least only with difficulty. Usually it was a mistake to try to handle goods to and from the transit shed by road ehicles at places where railway lines existed; that applied whether the rail track was a unning or a standing line. There were, of course, many cases where it had been done or ttempted, but most of such layouts had been built before road handling assumed its resent proportions. In a modern layout there was usually no need for such an arrangement; road and rail handling could be kept separate, although sometimes one was apt to vonder if those responsible for goods handling in ports were not subconsciously perhaps eluctant to believe that handling by road might require different arrangements from andling by rail. Railway lines for shed working must be at or towards the rear of the hed, but road vehicles could work equally well at platforms at both ends of sheds. For ingle-storey sheds such an arrangement was now almost essential, at least where any arge proportion of the goods was still handled by rail. For multi-storey sheds the referable arrangement was to provide for handling goods cleared by road from the ground loor from platforms at the ends of the shed, and from upper floors from the outside of an sland platform at the rear of the shed; and to provide for handling all railed goods at one or two) tracks between the island platform and the shed floor, railed goods from the round floor being loaded on the shed side of the tracks, and from the upper floors on the sland platform side of the tracks. That arrangement allowed both road and rail handling o proceed independently, as mentioned by Mr Matheson.

Finally, there were one or two detail points which he wished to mention:—

(1) The width of quay of 65 ft noted by Mr Matheson was good, but 75 ft was better.

(2) The slope of the floor of 1 in 100 mentioned by Mr Matheson meant that with a shed 150 ft wide there was a difference in level between the rail tracks at the rear of the shed and on the quay, and that the rear tracks would probably be depressed below the general road level. Either of those conditions was very inconvenient; he asked the Authors whether the slope of 1 in 100 was decided upon by the fork-lift truck manufacturers' requirements or not. A slope of 1 in 50 enabled a much better loading arrangement to be got.

(3) It was arguable whether continuous sliding doors were really an advantage. They were neither so secure nor so weatherproof as a series of fixed doors, and they did not give any more stacking space.

(4) On the question of design of ships, he asked Mr Lees whether it was possible to increase the size of hatches in view of his comments about makeshift arrangements used in ships' holds.

In that connexion, and indeed on the general question of cargo handling, he said a considerable amount of work had been done by the International Cargo Handling Co-ordination Association, but British representation so far had been rather lacking in that organization.

Lt-Col. R. H. Edwards (Civil Engineer, South Wales Docks), said that Mr Lees referred presumably to a Liberty ship, of which there were still a great number trading; but since they would soon reach the end of their economic life, some other type of ship would be needed to replace them. Would Mr Lees express an opinion as to what he thought the cargo ship of 10 to 15 years hence would be like? Was not the naval architect's problem one of gaining maximum bulk with the minimum weight? Oil tankers and ore carriers had their machinery aft; could not that arrangement be adopted for general cargo liners? It would give an unrestricted area throughout the length of the ship for cargo spaces and hatches, and he felt should facilitate work at the ports and speed up the turn-round of the ship.

Mr Matheson's Paper was of particular interest to those who were called upon to prepare schemes for modernization of the older ports to meet present-day needs of commerce and, in his own case, the change from coal exports to general cargo.

There could be no hard-and-fast rules as to what one should do, because each situation required an individual appreciation and careful consideration to meet the requirements of the shippers and to suit the site available for development. The Author made particular reference to road traffic, which was causing much concern at certain ports, for that transport had descended upon many of the older docks, originally laid out for rail service. Road traffic had to use many ports ill provided with good road access, and something should be done about it. That was the concern not only of the dock authority but of the local councils, since any road improvement schemes should take into account the road approaches to and from the port, which were the responsibility of the council. Close co-operation was vital.

Congestion around quays and sheds by road vehicles was well known, but did not occur with rail traffic because there was proper provision for dealing with it. Why should not provision be made also for road vehicles? For rail wagons there were reception and regulating sidings, so why not vehicle parks *en route* to the sheds for road vehicles? Such parks could hold the vehicles until called forward by telephone or some such control, thus avoiding congestion around the sheds and blocking of the roads.

Much could be done to improve congestion by the shippers in spreading the arrival of export goods to make a more even delivery to shed or ship, during the time the latter was loading.

A debatable problem was whether shed floors should be at quay level or at rail-platform height, and he would like to hear the Author's views on that. For export traffic it was desirable that road vehicles should be able to run into the shed from the roadside.

The Author recommended that doors should be continuous along the face of the shed, but with that he could not agree. He considered that alternate door openings and solid wall were preferable, if only to save maintenance of the doors, which could be slid behind the walls for safety. Timber doors were preferable and rolling shutters should be avoided because they were very vulnerable and costly to maintain.

On the subject of quayside cranes, in the United Kingdom crane makers influenced port design, for their general practice for many years had been to design cranes on tracks of, say, 13-ft-6 in. to 20-ft gauge. The cranes took up, therefore, quite a considerable amount of quay space. He wondered why the type of crane substructure common on the Continent was not more used. That type of substructure had the front legs on a single track behind the coping and the other end supported on the front wall of the shed, the crane superstructure being carried on girders joining the legs and the shed. That arrangement gave an unrestricted quay wide enough for four or five rail tracks. Would the Authors of the last two Papers express their views on that?

Mr J. T. Williams (Divisional Engineer, Port of London Authority) wished to make a few brief remarks first on Mr Tooth's Paper, and then to raise one or two detailed points on Mr Matheson's Paper.

Mr Tooth had mentioned that the introduction of mechanical appliances had in some cases led to dramatic results; it was no exaggeration to say that the fork-lift truck and the mobile crane had caused something of a revolution. There was no doubt that one fel

lifferent tempo, a different kind of rhythm altogether, when watching a fully mechanized ay in operation. He wondered why that had taken so long to come about. When idying the subject, he had referred back to a Paper by Binns[1] in 1932, in which it d been mentioned that the average working effort of a dock labourer was about $\frac{1}{10}$ h.p. ith a normal dock labour gang, there was about 1 h.p. in operation as the unit of power. was also mentioned in Mr Binns's Paper that the manual handling of goods was 100 nes more expensive than doing it mechanically. Now there was the fork-lift truck, iich could develop about 35 h.p.

He thought the reason for delay in introduction of mechanization as one saw it today s partly the high capital cost of the special plant and partly the difficulty of keeping reasonably fully employed. That applied particularly to quay cranes and other static pliances. But mobile cranes and fork-lift trucks had changed that, because they were ry versatile machines which, because of their mobility, could be kept reasonably fully ployed enabling cargo to be handled more speedily, thus justifying their introduction d existence.

A very big improvement in handling of cargo should be expected when using a 35-h.p. it instead of a 1-h.p. unit; speeds of handling had been increased by about 30%, so one s told, but he felt that the fork-lift truck would be capable of doing much better than at when the other links in the chain, such as the design of ships and sheds, had also been proved. He thought therefore that Mr Lees's opinion, that a fundamental change in e design of the ships was unlikely, was disappointing.

Mobile cranes and fork-lift trucks might be expected to require in proportion more aintenance and quicker replacement than other items of dock plant. Bearing that in ind, he thought the overall economic picture should be considered. Could Mr Tooth ve some further indication of the economic aspects of the mechanization which he had scribed so vividly? Were those benefits about which Mr Tooth had spoken, important they were, limited to the quicker turn-round of ships and the greater use of shed space? the end of the Paper, Mr Tooth hoped piously that some of the benefits would be passed to the consumer. Was there any real hope of that?

Mr Tooth had emphasized that, because of the introduction of mechanical tools, berths ould be constructed on a new pattern, and Mr Matheson had also stressed that space ould be left for accommodation of mobile plant, pallets, and so on. He suggested that might be advantageous to provide about 20 ft between the rear of a shed and the nearest il track. That space could then be used for stacking pallets and other gear, and for erating mobile cranes, whilst leaving both rail tracks and roadway clear. He thought so that, in view of the cost of construction of loading banks, unless the ground levels re particularly favourable, loading banks should, if possible, be dispensed with.

On p. 251, Mr Matheson stated that "Consistent with fulfilling its proper functions as a fe coverage for goods, a transit shed should be of the lightest and cheapest type possible ithout incurring heavy and constant expenditure on maintenance." Goods had to be otected from the elements and he thought that one of the elements which the dock gineer was very conscious of was fire. What sort of fire grading of buildings would Mr atheson recommend? In the case of a multi-storage shed with upper floors used for arehousing, the fire load, even for contents of average calorific value, would be considerle, and consideration would have to be given to constructing fire walls to divide the shed alls into suitably sized compartments. That might limit the use of fork-lift trucks, cause the maximum size of doorway permissible in a fire wall did not allow the passage such machines. In some cases verandas could be used for access between compartents, but that might not always be convenient or possible. There was a case for vestigating the possibility of allowing larger fire doors by the carrying out of suitable ll-scale fire tests.

Mr Matheson had suggested that the use of structural steel in two-storey sheds might be advantage. To what extent did Mr Matheson consider that the steelwork should be

[1] Asa Binns, "Recent Developments in the Mechanical Equipment of the Port of London thority." Proc. Instn Mech. Engrs, vol. 122, p. 575 (May 1932).

protected from the fire protection point of view; when should sprinkler systems or dr[y] rising mains be used; or a warehouse given full protection by the adequate covering [of] all steelwork? Some fairly recent dock fires had given prominence to that problem.

There was one last point on which he hoped that Mr Tooth might be able to give [a] little more information. In a recent article in the press, a shipping concern had said tha[t] before the second world war their ships completed three voyages a year and that 5 yea[rs] ago those had been reduced to 2·25 and in 1955 to only 1·9. To what extent, he wondere[d,] was that because cargo ships were getting larger and possibly were loaded deeper, bot[h] inwards and outwards, and therefore tended to spend more time in port?

Mr F. D. M. Gamble (Chief Mechanical Engineer, Samuel Williams & Sons Limite[d]) said that he had been surprised to find how many similar problems there were in the larg[e] organization which Mr Shire represented and the smaller organization at Dagenham Doc[k]. He would like to swop experiences with Mr Shire on many points raised in the Pape[r] but proposed to confine himself to one aspect of grabbing cranes which might be [of] general interest.

At Dagenham Dock there was very high emphasis on bulk discharge and considerab[le] enthusiasm for the improvement of both equipment and methods of operation. I[n] 1938 delivery was taken of three grabbing cranes of 7½ tons capacity and 70 ft radiu[s]. They were equipped with 150-h.p. hoist motors and had a hoisting speed of 200 ft/mi[n]. Those cranes had been regarded as highly satisfactory at the time, being better tha[n] anything previously used in the dock, and were still giving yeoman service. Howeve[r,] since after the war there had been a demand for additional cranes, it was felt that advan[-] tage should be taken of experience during the war years. Many innovations we[re] embodied in what was virtually a standard crane, and the first post-war machine wa[s] delivered in 1948. It had a 200-h.p. motor and a hoisting speed of 250 ft/min.

When the crane was put into operation, it had been with some embarrassment an[d] disappointment that they had found very little increase in rate of discharge despite th[e] higher hoisting speed. It was found that money had been spent on a bigger motor an[d] higher torque, but that unfortunately a lot of inertia had been bought as well. The ne[w] crane accelerated more slowly than the old machines.

Fortunately there had been an opportunity for them to recover their self-esteem[.] They were just starting to use at Dagenham a crane of about the same capacity of 7[½] tons, and in the design stage had put great emphasis on the reduction of inertia. Tha[t] crane was arranged to give a hoisting speed of 400 ft/min.

Fig. 37 showed a comparison between the accelerating speeds. The immediate post-wa[r] crane actually took longer than the pre-war crane up to 21 ft, where the two cranes had the same hoisting time. After that, the more powerful crane started to make it[s] way. The new crane just being put into service accelerated by comparison at an enormou[s] speed and went on hoisting at 400 ft/min. A 21-ft hoist, that took 7½ sec for both th[e] older designs, was accomplished in approximately 4 sec with the new crane—a substanti[al] improvement. The graph, however, was not entirely realistic, since it assumed that a fu[ll] grab was lifted from rest, whereas in practice the hoisting motor gathered momentum during the process of closing the grab.

The new crane had other interesting features. In the control cab the driver sat wit[h] a glass panel beneath his feet and he had miniature joystick controllers for the hoist an[d] the combined slew and luff. The cabin was symmetrical with the jib, the jib bein[g] bifurcated or straddling the cab. The driver had an excellent view on both sides an[d] underneath. Also in the cab was a recording/weighing machine which had been develope[d] about 7 years ago at Dagenham, and was he believed still the only machine of that typ[e] which was automatic. It needed no weighman and it added up the net weights of eac[h] grab-full and recorded them on a paper strip.

In addition to making the cycle of grabbing quicker, it was equally important to li[ft] up as much material as possible with each cycle; that depended upon grab design. [A] port owner spent many hundreds of thousands of pounds on quays, jetties, and ancillar[y] services, but the whole turn-round of ships at a bulk-discharge port depended on th[e]

utput of the grabs which, by comparison, were cheap items, the price being less than 1,000. It was poor economics to use a grab constructed too heavily in attempting to ave money on grab repairs, or to use a grab which was designed for material having

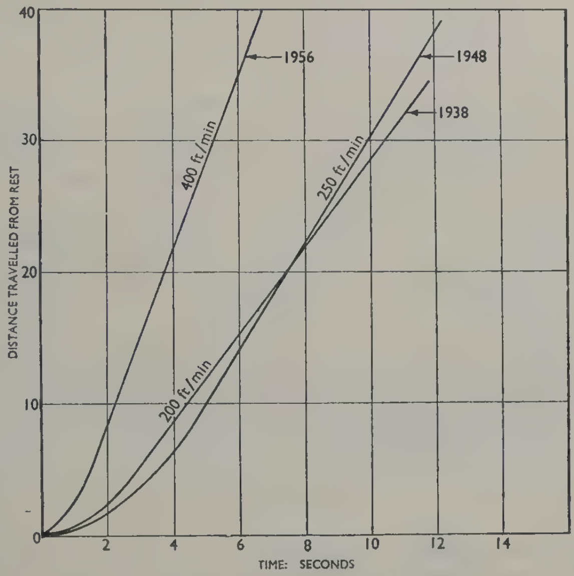

Fig. 37

ifferent characteristics or different density. For that reason, he was interested in Mr hire's remarks with regard to the all-aluminium grab, and he hoped that when it came nto use Mr Shire would make the information available.

Mr N. N. B. Ordman (Divisional Engineer (Civil), Port of London Authority) said hat his remarks were confined to the Papers by Mr Tooth and Mr Matheson. The variables underlying problems of cargo handling were very numerous, so that an analysis f all the factors concerned was rather intractable. Mr Matheson stated at the beginning f his Paper that anything in the nature of a general specification could not be drawn up; hat must be accepted. But he was not convinced that the variables were so numerous nd so dissimilar that they were not susceptible to some degree of rational analysis to greater degree than was normally attempted.

The sort of thing he had in mind was a correlation between the size of ship, the type of argo, and the size of transit shed required to give the optimum and most economic ervice. Such a correlation should be based on the analysis of a very large number of hips and a large number of different types of cargo during many years.

An investigation of that kind had been done and the results recently published in onnexion with the design of a general-cargo berth at the Port of New York. Indeed, t was the type of study that must precede the design of any new port. He thought, owever, that it should also be carried out as routine at British ports to establish trends nd to produce data on which to base developments.

The length of the transit shed was normally determined in relation to the length of the hips using the berth, but with the conception of continuous roofing over the full length f a multi-berth quay a greater degree of flexibility was available in that dimension;

with the development of mechanical-handling equipment the trucking distance was no longer such a rigid criterion, and that gave greater flexibility in the width of the shed. With greater flexibility in those two dimensions, the area of the shed was no longer so closely determined, and it became necessary, therefore, to evaluate other criteria.

If more data were available it might be found that there was a tendency for the area now provided to be rather less than the optimum, and, with the restrictions on the area available for dock development in the United Kingdom, he thought that forced them to give more attention to multi-storey sheds.

With multi-storey sheds the problems of cargo handling became more involved. On the quayside the difficulty was not so great, because where there were quay cranes they could without difficulty, as Mr Matheson had indicated, land goods out of ships on to the upper floors. On the land side, however, the problems of delivery to road and rail and from road and rail were more difficult. To meet that problem reliance must be placed on the ingenuity of those who designed mechanical-handling tools.

Mr Matheson had given some factors of the cost of multi-storey and single-storey transit sheds; those figures agreed with others which he himself had obtained, but they did not take into account the cost of extra land involved in a single-storey transit shed compared with a multi-storey transit shed with the same floor area. In many cases he thought that would be very important.

In that connexion there was a significant point in Mr Tooth's Paper; he had said that with the development of mobile handling equipment not only should ample space be provided within the transit sheds, but large open spaces should be provided outside and around those sheds for wide roads, parking areas, and offices. The provision of those large areas was often difficult and sometimes impossible, and the obvious solution was development in height. A realistic appreciation of the economy of that type of development, he felt, could not really be made until more of the research of the type he had indicated had been done to provide the data needed.

Mr R. R. Verner–Jeffreys (Assistant to Road Motor Engineer, British Railways, Western Region, Slough) said that he would confine his observations to Mr Shire's Paper because it dealt with the subject with which he was more closely associated.

Mr Shire had referred to economy in operation of cranes with diesel instead of petrol engines. In the undertaking with which he was associated, a number of mobile lifting appliances, mobile cranes, and fork-lift trucks, had been converted from petrol to diesel. They had found that fuel consumption with the diesel engine was approximately $\frac{1}{4}$ of that of the petrol-engined vehicle. Since diesel oil was untaxed, fuel costs would be only about $\frac{1}{8}$ with the diesel-engined appliance compared with the petrol-engined appliance.

He agreed wholeheartedly with Mr Shire's opening observations on accessibility, particularly with the fork-lift trucks, from the point of view of maintenance. It had been his experience, however, that with the diesel-engined appliance many problems previously encountered with the petrol-engined machine had been overcome, as a result of the different characteristics of the diesel engine.

Mr Shire had referred to engine overhauls. It was his experience that on diesel-engined machines the injectors did require attention every 500 hours, as Mr Shire stated, but he suggested that the removal of the cylinder head in those intervals should not be necessary if heavy-duty lubricating oils were used. He had found that it was quite normal for a machine to operate between 1,000 and 2,000 hours before it was necessary to remove the cylinder head; the removal of the cylinder head was dictated by the valve seating condition.

Reference was made in the Paper to a complete stripdown every 2,000 hours. That had not been his experience. With the use of heavy-duty lubricating oil an engine life of 5,000 to 6,000 hours could be expected. To obtain that life, he agreed, it was very important to ensure that engines had efficient thermostats to keep the cooling water at a reasonable temperature.

On p. 275 costs of various repair items were, he thought, a little high. He thought that for regrinding an average-size diesel-engine crankshaft 7*s* 6*d* per pin was nearer the mark.

On p. 257 there was a reference to metallic tires. His undertaking had used those tires

in recent years on mobile cranes and found them very satisfactory. On cranes with the castor wheel at the rear the 90°-lock could still be obtained despite the tire being pneumatic, whereas with the normal conventional pneumatic tire it was necessary to restrict the lock, in the case of the appliances he was thinking of, to 64°, which was a severe operational embarrassment. How had Mr Shire ensured that the pneumatic tires were kept at the correct pressure? He presumed that was done daily.

Lastly, in regard to the reference to up-turned exhaust pipes on p. 257—to which Mr Tooth had also referred—he had encountered difficulties with that also. When fork-lift trucks were working in confined spaces, as in warehouses, up-turned exhaust pipes had been fitted to keep exhaust fumes away from the driver. On the other hand, on some of the heavy-duty fork-lift trucks with up-turned exhaust pipes working in open yards it had been found that the exhaust gases got nearer to the driver than when the pipes were left below in the conventional position. He thought that the position of the exhaust pipes was very important but required more research to find the best position for them.

Mr R. F. McBride (Mersey Docks and Harbour Board) said that he was particularly interested in Mr Shire's Paper. It was part of his duty to maintain diesel and mechanical appliances. In Liverpool there was a similar problem to that mentioned by the previous speaker and it had also been his experience that diesel engines went 5,000, 6,000, or 7,000 hours quite commonly without a major overhaul.

Mr Shire had mentioned tubular jibs, which were now becoming quite common. There were none at Liverpool, however, and he wondered whether the Author could give some information on the ease or cheapness of repair compared with the conventional jib.

With regard to the diesel crane, he had been surprised at the period of 5 years mentioned as being necessary to recoup the £1,200 cost of converting to diesel from petrol. At Liverpool they had recently converted thirteen 5-ton cranes from petrol to diesel, and they expected to get the money back in about 15 months. The figure involved was more than £3,000.

A point he had not noticed in the Paper with the diesel crane was the question of a spark arrester on the exhaust pipe. He had found that most silencers as received from the makers were very inefficient with regard to spark arresting. If a crane was working in a shed containing cotton or anything inflammable, it was essential that an efficient arrester be fitted.

In the Paper, he had not noticed any record for wire-rope examinations. He assumed that they were carried out daily in the normal routine examination.

Another point that had puzzled him was whether to use anti-freeze in winter, or to insist that radiators should be drained every night. That was not often mentioned, but there must be some system of protection for the plant.

In regard to greasing or oiling of the plant, anybody with a large number of mobile machines realized that greasing and oiling was a very important but difficult job which had to be carried out regularly. Mr Shire had mentioned 35 min for oiling. Did that refer to one crane—or to how many cranes? At what time of the day could greasing be done? The crane could not be taken off its job, and to do it outside working hours meant overtime and high costs. At Liverpool the driver was made responsible for that operation. Each driver was, so far as possible, kept to one particular crane, and it was part of his job, before going to work in the morning, to carry out full greasing operations.

Mr Colin Hammersley (Chief Mechanical and Electrical Engineer, John Laing & Son Ltd) said that he would confine his remarks to Mr Shire's Paper. Mr Shire made it clear in his introductory remarks that the important thing was to apply the correct machine in the correct fashion. To that he would like to add, from his own experience, that it was essential to carry with one the people who were going to use the machine, from the manager to the operator. The technical problems were relatively easy, but problems of ensuring that the people who were going to operate a machine were fully conversant with the benefits to be derived, and were in tune with oneself, were more frustrating.

There was reference in the Paper to tubular steel jibs. He was delighted that Mr Shire

had emphasized that, because he did not think that nearly enough use was made of tubular structures in the United Kingdom. With welding tubular constructions could now be made in a way not previously possible. A common way of producing an elegant structure was to use tubular steel for crane jibs. There were some fine examples in existence, but unfortunately some of the largest crane manufacturers still used the old methods. Rivets were often used rather than welded joints.

In regard to saving in cost, he quoted an example of the use of tubular steel versus conventional methods which had concerned a large and well-known crane and plant manufacturer. The example was not a crane, but another type of structure. He had designed a structure making use to a large extent of tubular sections, and had submitted it to the manufacturer with a request for their price for making it. The price given had been about 90% more than the estimated cost of making it in his own firm's workshops. He had been so worried about it that he had taken it up with the manufacturers' design department and found that whereas his design required 5½ tons of steel, the manufacturer had estimated the use of between 12 and 14 tons. His firm had made the equipment themselves, and it had been working on sites for 3 or 4 years.

A good example of the modification of plant mentioned in the Paper was the crane for timber handling. First, there was the question whether, and if so by how much, the crane was derated for that particular duty? Possibly it was derated 25%. Having derated it was there any extra counterbalance required on the rear? What was the tire pressure and also, if it had been derated, was any step taken to take advantage of that fact by putting in smaller operating motors? In other words, had the modification of that crane in the way described been justified, or would a machine purpose-made for the job have been more suitable? Of course, that question was tied up with whether the crane was required for normal purposes as well.

He noticed that an example was given of conversion of steam cranes to diesel hydraulic. Had diesel-electric operation also been considered, and, if so, was that method considered less attractive?

There was an interesting solution to a roof handling problem given near the end of the special-purpose section of the Paper, i.e., the transporter. How was the transporter moved between one flap and the next? Did a man have to climb up on the roof to reach the control, did he do it by swinging the pendant between adjacent flaps, or how was it done? If the man had to go on the roof, there might be possibilities for development of a system of push-buttons, one at each flap to control the movement of the transporter between adjacent points. Quite easily an interlock on the pendant could be provided to stop the transporter being moved by an unauthorized person from any other flap position.

Fig. 21 showed a small truck of tubular steel sections. He would like to think that the manufacturer had not given his last word, since it did not appear the most elegant design possible in that sort of truck. He presumed it was a proprietary article.

Referring to maintenance, in the organization with which he was at present connected they had found it useful to have mobile plant inspectors visiting the working areas, which admittedly were widely dispersed, to check maintenance of plant. Did Mr Shire think that would be an advantage inside a confined working area as at the docks, which were fairly close together from the point of view of supervision?

With regard to the testing of cranes and appliances, did Mr Shire's organization find it worthwhile having a set of standard test weights to carry out their own Statutory tests on lifting appliances every 12 months, or did they have that done from outside?

He also wished to refer to mild-steel slings and lifting tackle. The use of alloy slings was no doubt satisfactory in a confined space where the type of lifting tackle could be controlled, but there might in some cases be a danger of mild-steel units being mixed with ones in alloy steel and the heavier load thus being lifted with the mild-steel sling.

With regard to the hiring of plant, he could only quote his own experience. Mr Shire's suggestion that the operating company should hire plant out to its own users was practised fairly generally throughout the civil engineering industry. Why could it not be applied in the same way at the docks?

Mr E. Loewy (Senior Engineer, Sir William Halcrow & Partners, Consulting Engineers) said that he wished first to ask, in regard to Mr Lees's Paper, why greater use could not be made of side-entry loading into ships to eliminate the quayside crane which, though forming an essential link in the handling chain, was a link which made the loads move in the wrong direction. Such side-entries would enable a fork-lift truck or small lorry to run straight into the holds. He believed that certain small ships in Denmark had that provision, but why could not the practice be adopted on a wide scale for general cargo handling on ocean-going vessels?

Turning to Mr Matheson's Paper, he was glad that, although at the outset the Author said that an idealized layout for ports could not be considered, he did proceed to show one such conception. Such things were valuable because many engineers were from time to time concerned with construction of new ports, and could not then be guided by local practice, because it did not exist. He thought that the layout in Fig. 2, Plate 3, was very interesting but it rather begged a basic question not mentioned in the Paper, namely, the relative merits of berths laid in a long line along the margin of a water area and berths in the form of fingers or jetties set out at an angle into the water area. The type of layout that the Author showed was not normally possible on a finger form of construction because the width could not usually be obtained at a reasonable cost. Such things as warehouses had to be put somewhere else. But even on the Author's own layout no provision appeared to have been made for the easy movement of goods from the ship's side or from the transit shed into the warehouses. A complicated movement seemed necessary instead of a direct transfer straight across. The system of railway lines to each berth seemed to cut across the movement he had in mind, and also seemed to interfere with the necessary end-loading of the transit sheds, which was normally the only way in which lorries could get to transit sheds satisfactorily.

That brought him to the difficult question of making provision for lorry access to transit sheds. Everywhere in the world it was necessary to face the fact that road traffic was going to increase, and yet the ordinary conventional transit shed, which might be 500 ft long and 100 to 150 ft wide, did not readily lend itself to lorry access except at the ends, where the volume of goods that could be handled was very much less than down the sides. Lorries could not be manœuvred easily in a direction parallel to railway wagons, and therefore the long length of the shed was normally difficult to use. That problem became more troublesome with multi-storey sheds. He would like to have the Author's views on the possibility of allowing lorries to drive into the sheds, as was sometimes done in very large sheds in France. That also tended to eliminate the need for the platform at the back of the shed, which had been commented on by other speakers.

In regard to crane jibs being zinc-sprayed or shot-blasted, he thought that the Author's comments would probably apply only to the United Kingdom. Certainly in tropical countries, with severe corrosion, galvanizing or even the use of aluminium jibs was often justified. He wondered why British crane manufacturers seemed so conservative in their designs. Post-war British cranes looked very much the same as those 25 years old, despite improvements on the mechanical side. However, some of the persuasive German advertising literature seemed to show a radical re-thinking of the form that a cargo crane should take.

Mr J. P. M. Pannell (Engineer to Southampton Harbour Board) said that with regard to the column spacing problem, he thought that Mr Tooth put the matter very cogently when he used the words "a reasonable approach".

He wished to refer mainly to Mr Shire's comments. An ultimate shape of the joystick type of control seat for cranes had had rather astonishing repercussions. It looked too much like a comfortable club chair, and certain policy-making bodies seemed to think that a club chair was not suitable for a crane driver to sit in. The final shape was to some extent a logical conclusion, and although it looked the way it did, it was a highly efficient way of using the driver's effort. He thought that ultimately that type of thing would be adopted.

There was one rather surprising effect of the improved efficiency with which his authority was struggling at the present time. Unlike a large authority which had absolute control of its power supply, his authority had a supply from the local electricity board, and the question of diversity was coming in. With increased efficiency the diversity was getting narrower and narrower, and it was sometimes found that the breakers were coming out at quite frequent intervals.

As regards painting, there had been no mention of flame de-scaling, and he thought that some comment on it might be worthwhile.

Mr R. G. Taylor (Assistant Chief Engineer, Tubewrights Ltd) said that it had been music to his ears to hear Messrs John Laing's representative pleading for more tubular structures. His own organization had been pioneering tubular structures for many years, and he felt that even now sufficient interest had not been shown in that new development.

The repair of tubular jibs had been mentioned by the speaker from Liverpool, who had made a classic understatement in saying that they were becoming popular. They had been in use for at least 14 years. The first tubular jib had been a 30-ft one and it was still in use although very much sub-standard by present practice. Tubular jibs were being made literally by the thousand, and were being used all over the United Kingdom by some of the most reputable crane manufacturers.

Types of jibs and what one could do with a tube were very interesting subjects. Joints on to surfaces at any angle could be made without any difficulties of fabrication. That meant that one could use the triangular jib, which was a completely self-bracing determinate structure, without any difficulty in the shop. That type of jib could be made economically in any other type of section. It could be made with rolled steel angles and gussets, but the cost of forging and building gussets or angles prevented it being economic.

As regards maintenance, assuming that the initial prices of the steel jib in the old-fashioned type of steel compared to tubular steel were the same, there was straightaway a very much smaller problem from the maintenance point of view. With the tube itself there was virtually no area for deposition of dirt and corroding materials. Furthermore throughout Britain there was happening the sort of thing which he was sure, as engineers, they would agree ought to be banned. Pieces of angle were separated with a $\frac{3}{8}$-in.-thick piece of plate; it was spliced. Not only was it filled up with gusset, but a cover plate was put underneath. Dirt got in and could not be got out, nor could it be cleaned; if it could be cleaned, it could not be painted.

Apart from the surface area itself, it would be found that job for job the tubular material would give about a 40% or more reduction in area. Figures were quoted in Mr Shire's Paper for shot-blasting and painting jibs. He did not know whether the prices given for painting and shot-blasting and so on were for a tubular job, but the cost of such work was £500 for 3-ton and £675 for 5-ton cranes. Although painting was done only once in 15 years he suggested that if the area was instead at Beckton gasworks a new crane would be needed after probably 7 to 10 years at the most. In other words, Mr Shire's figures were only comparative for one part of the country. It could not be said that jibs were to be painted once every 15 years any more than it could be said that they were to be painted every 2 years. The thing to bear in mind was that every time they were painted the less area one had to paint the more economical the job became. If $\frac{1}{3}$ the area to be painted could be saved and three coats were used, the saving was one coat of paint per job.

Not enough attention was paid to protection of cranes. Many sorts of protected steel were obtainable nowadays. Most people were aware that red lead was not the best protection, particularly in seaside districts. Why not use galvanized steel? Why not shot-blast and metal-spray the job? Why not shot-blast the whole lot? His firm had done structures of large span that could well have been storage sheds, where they had saved so much surface area that it had been an economic proposition to shot-blast and metal-spray the whole thing at no more cost that it would have cost to paint the orthodox structure.

On the question of column spacing, it would be possible to have a completely tubular-framed storage shed of 100-ft clear span, 16 ft 8 in. grid, at about 22 lb/sq. ft. If something bigger was needed, there was the 220-ft span and 40-ft grid at less than 7 lb/sq. ft. A larger size was 150 ft × 140 ft at less than 8 lb/sq. ft.

All he pleaded was that those who were at that very moment sitting on one of the revolutions that had taken place in Britain—a welded tubular support—should in their own interest try to apply the same principles to their structures both on the dockside and anywhere where steel was used.

Mr W. J. Sivewright (Assistant Engineer (Civil), Port of Bristol Authority) noted that Figs 2 and 3, Plate 3, of Mr Matheson's Paper showed alternative arrangements of cranes in relation to the front of the quay. At first sight, whatever the structural reasons for the arrangement, that shown in Fig. 2 appeared to give the driver a better view of the hold and the hatch. In fact, however, in discussing the matter with drivers he found that they preferred the arrangement shown in Fig. 3, because they did not have to peer down at such a vertical angle. Of course, the difficulty would be overcome by the insertion of a floor panel as in Samuel Williams's crane. That did bring to mind the point that in design some regard should be given to the preferences of operators, particularly because dock operators and employees were rather sensitive plants. Their preferences might not be valid, but the psychological effect undoubtedly had some bearing on efficiency of operation.

The remainder of his remarks would be confined to Mr Shire's Paper. Palletization had been very much in the forefront in the discussion. The maintenance costs quoted by Mr Shire appeared high. The Port of Bristol, with a holding of about 3,500 all-timber pallets, had returned to shop annually about 140. Of those, about 25 were scrapped and subsequently replaced, and the remainder were repaired at an average cost of £3 18*s* each. The cost of renewals and repairs together worked out at 3*s* 6*d* per annum per pallet, or 3% on the capital cost. Obviously wear and tear depended on how much the pallets were used in transport compared with their use in storage. Could Mr Shire relate his costs to ton-lifts or even to the number of lifts per pallet? A factor which might be involved was the number of pallets per truck. The Port of Bristol held 200 pallets per fork-lift truck.

Except in Mr Matheson's Paper, there had been little mention of dispatch from upper floors of multi-storey sheds by gravity chutes, box slides, and the like. Would not some such arrangement have obviated the expensive arrangements referred to at the bottom of p. 260 of Mr Shire's Paper? There was a case at Avonmouth where two sheds had been provided with rear roof cranes which had never been used because there were more favoured facilities for getting goods out of the shed by gravity on the roadside.

With regard to the painting of cranes, in spite of Mr Taylor's remarks he agreed with Mr Shire that, generally, expensive preliminary preparation on a new crane was scarcely justified. Care should be taken, however, when the crane was new, to watch that it was not going to handle highly corrosive goods by grab. Breakdown of painting could occur at a very early stage in such circumstances.

Mr Shire mentioned that d.c. cranes had proved satisfactory. Was one to read that as a preference for d.c. cranes against a.c.; if so, would Mr Shire give his views on that matter?

Finally, he felt that Mr Shire's costs of maintenance should be taken as general rather than particular. To take the case of an oiler, surely the cost of oiling on the class of plant referred to depended very much on the distribution of plant about the dock estates and the extent of the docks estates?

*** **Mr G. A. Wilson** (Chief Engineer, Port of London Authority) observed that the Papers gave a good account of current practice and as such would be most helpful. Mr

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*** This and the following contribution were submitted in writing after the closure of the oral discussion.—Sec.

Tooth, almost alone among the Authors, had speculated about the future and that was particularly praiseworthy because he knew the many difficulties encountered in the introduction of new methods. Mr Shire had also looked into the future when he anticipated that ultimately the main source of power would be electricity generated atomically.

Mr Lees was, however, conservative; he did not expect much change, but it was known from experience, sometimes rather costly, that changes in ship construction were continually taking place and Mr Wilson believed the clue lay in conclusion 10 of the report of the British National Committee of P.I.A.N.C. on the depths to be provided in seaports, which stated:—

> "There is no evidence of a continuing general trend to increase the size of all types of ships. Where increases are taking place they are in respect of certain trades only. In these trades, under the influence of economic considerations, the smaller sized vessels in each class, however, tend to be replaced by vessels of greater dimensions. Such increases are determined partly by the requirements of the trades concerned and partly by existing or projected port facilities."

The idea there was that the largest and therefore probably the newest vessels in each class did not change very rapidly, but when smaller vessels in a class were replaced, new developments were always incorporated and those were the changes which were felt by Harbour Authorities.

Perhaps Mr Lees would admit that there were at least three features which Mr Wilson had noticed and which had been mentioned by other contributors which might be forerunners of more extensive development. The first was the siting of the engines aft, as in the *Southern Cross*. Craig had shown [2] that there were many difficulties to be overcome, especially with trim, but with the reducing weight of main engines, the layout which permitted a long clear hatch might become attractive to shipowners and might make the introduction of mobile cranes mounted on a carriage on rails spanning the hatch west worthwhile. Mr Loewy had mentioned the coasting vessels using Copenhagen, which had doors in the side, the quay being equipped with a ramp which was set to meet the level of the doors. The fork-lift trucks ran up the ramp and through the doors, descended in lift to the required deck, set their palletized cargo, and returned to the shore. Those particular coasting vessels operated on a regular time schedule and the mechanized handling of cargo was justified by the regularity which it ensured.

More determination to reduce the cost of handling goods was necessary in the transport industry. At present the recognized procedure was to pass on any increased costs resulting from labour demands to the manufacturer or the consumer.

The Minister of Transport had now refused to allow the British Transport Commission to continue with that easy method, presumably because the unions had agreed to co-operate in increasing efficiency when accepting the wage increase. The results obtained in the electricity supply industry had demonstrated that it was possible to offset rising costs by technical development, but it had to be acknowledged that technology played a predominant part in that industry.

The great merit of Mr Tooth's Paper had already been mentioned, but how much richer it would have been had he been able to say, as a port operator, what savings he had been able to make as a result of technical developments in ships, handling appliances, and buildings.

Undoubtedly the first step had to be a reduction in the quantity of labour employed and in that connexion Mr Wilson suggested that mechanization should not stop with handling, but should also include methods for reducing the number of staff required for tallying and for the making and sending out of accounts. On the latter point, was it worthwhile considering a uniform charge per ton of goods handled, with the object of reducing the number of checkers and clerks?

Admittedly the days had gone when, because of technical improvement, labour could

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[2] R. K. Craig, "Passenger liner with engines aft". Trans Inst. Mar. Engrs, vol. 67, 1955, p. 439.

be wantonly discharged, but with the present chronic employment position it should be possible to arrange for every improvement to be accompanied by some reduction in the amount of labour employed.

Mr Max Bentham (Consulting Engineer) regretted that Mr Shire had restricted his remarks on plant maintenance to what he termed "mobile cargo handling equipment".

The system outlined by Mr Shire was in keeping with experience and organizations used in large steel works for the same purpose.

Quay cranes were not included in the mobile plant covered. Whilst they were mobile plant it was realized that they differed from that described in that they could not be taken to the workshop; repairs and adjustments had to be made where they stood. It would be interesting to know if the Author had a similar system of inspection, short- and long-period overhauls, for those cranes. On the assumption that there were outworking gangs attending to the maintenance of quay cranes, did those men operate from the maintenance shop described in the Paper or from some other central works?

Ropes and chains featured so largely in dock handling equipment that the establishment of a department dealing with those items alone could be economical. The Author had mentioned that in well-established firms and large users of that type of equipment, such a department could be provided at a reasonable cost! Unless the regular inspection of wire ropes, slings, and chains were subcontracted to some competent organization, upon whom did the responsibility rest?

In a large Sheffield steelworks it had been found both economical and advisable for the firm to have their own department with comprehensive annealing and testing equipment, and to introduce a very tight system of identifying loose slings and chains, regular inspection, and recording of the maintenance of that equipment.

Could the Author indicate how effective control of those items was achieved in an area so widespread as most docks systems?

Mr Lees, in reply to Lt-Col. Edwards, said that the ship described in the Paper was not a Liberty ship (which was a cargo tramp) but a fast cargo liner, of which relatively few had been built in the United Kingdom towards the end of the 1939–45 war. Present British cargo-liner design was fundamentally similar to that shown in Fig. 1, Plates 1 and 2.

Turning to further points raised by Lt-Col. Edwards and by Mr Loewy and Mr Wilson, the Author's opinion regarding future design was contained in the last two paragraphs of the Paper.

Side openings might be quite valueless, say at a tidal dock (where, as at Southampton New Docks, the "rise and fall" might be 14 ft), and as for the basis ship, the difference between light and load draught was of the order of 20 ft. Cargo doors were not allowed below the waterline in Class I passenger ships.

Because of the requirement to fit transverse watertight bulkheads, it was not permissible in ocean-going ships to have undivided holds throughout the length of the ship and the siting of the main propelling machinery aft did not alter that.

In general cargo liners, the hatches were generally as long as they could be made without prejudice to other requirements; if owners considered that it was cheaper to install cranes longitudinally traversing such hatches, then such an arrangement would be adopted but the overall economy of such had yet to be proved except in certain specialized trades. If the hatches were made very wide, the hatch cover and supporting structure to carry the loading mentioned might require pillaring or might have to be of such dimensions and weight as would prove detrimental to the speedy working of proper stowage of the cargo; the longitudinal strength of the ship also had to be considered.

The naval architect's problem was to design a vessel which would enable cargo to be embarked, safely carried, and discharged with the utmost economy. How that was best accomplished would depend on many factors; it was agreed that one of them was a high ratio in terms of deadweight or cubic capacity to the actual weight of the vessel.

Mr Robinson had used the Author's figure, given in connexion with the strength of decks, to estimate requirements for storage space: the term "ton" was defined in numerous

ways and it was safest to check the context—a "measurement" ton occupied 40 cu. ft of space.

Mr Matheson, in reply, said that Mr Jellett seemed to be under the impression that he had said a 30-ft column spacing was sufficient for all purposes. That, of course, was not so. He had tried to make it clear that he agreed there were quite a number of cases where a much wider spacing should be adopted. His purpose had been to point out that if one could not, on hard facts, justify a greater spacing then there was no need to use it. He supposed that some of those present had seen the shed at Southampton, to which Mr Jellett had made reference, and in connexion with which a number of designs with different column spacings had been prepared. At the end of the day the wider spacing had been selected, and subsequently the shed had been greatly admired. But Mr Jellett had not stated the cost per cubic foot, and, after all, to a purely commercial concern that was really what counted. Unless it could be shown that extra revenue would result from extra expenditure then there was no justification for spending the money. At Southampton, of course, there was a prestige value in the case of the main passenger gateway to Britain.

The figure of 1 in 100 for maximum floor slope was considered desirable particularly where battery-operated trucks and other mechanical appliances were used, and also where high stacking was common practice. It was interesting to note that Mr Jellett had found no difficulty with slopes of 1 in 28 but such slopes should be avoided if at all possible in any new construction.

He agreed with Mr Robinson that there was a great need to reduce the time that goods remained in transit sheds. That was a very important point, because obviously the longer goods had to stay in shed, the greater the shed space required and the greater the cost involved to all concerned. That state of affairs often arose from poor shed clearance resulting from inadequate road and/or rail facilities for removing goods from port areas. Mr Robinson had also referred to the awkward shape of the sheds (Fig. 2, Plate 3). If, in fact, drawn to a larger scale, it would be seen that the "cut-off" at the ends of the sheds did not need to be as exaggerated as shown. Pallet stores and office and other accommodation could be incorporated in the awkward sections, leaving the more normal, and by far the larger, sections available for their proper purpose. The figure of 65-ft quay width for the conditions mentioned in the Paper was given as the minimum and Mr Matheson was in general agreement with Mr Robinson's comments on that point.

Lt-Col. Edwards had referred to the advantages of the "dot-and-carry" type of quay crane. At present he was looking into the possibility of constructing a shed, on a very restricted site, to replace an existing single-storey building which had become inadequate for the needs of the trade using it. To give the necessary space the new shed would require to have ground and first-floor transit accommodation, open cargo storage on part of the roof, and the remainder of the roof occupied by offices and a car park. Road and rail facilities were required both in front and at the rear of the shed. Obviously every inch of space was important and the use of "dot-and-carry" cranes was almost unavoidable in that case. Fig. 38 illustrated the difficulties of meeting all the desirable but onerous requirements which had been called for.

The point raised by Lt-Col. Edwards that for export traffic it was desirable that road vehicles should be able to run into shed from the roadside, was, of course, an illustration of the need to balance one requirement against another in any dock layout and select what appeared to be the arrangement which would give the highest proportion of economical use. The arrangement in the cross-section (Fig. 2, Plate 3) would provide one answer to the difficulty in the case of two-storey sheds where the upper floor would be used for export cargo.

Mr Williams had very properly raised the matter of fire risk in sheds. Mr Matheson had purposely refrained from comment on that point, for it had been impossible to cover it within the limits of the Paper, particularly since the restrictions mentioned by Mr Williams were not applicable throughout all ports in the United Kingdom. The subject, indeed, was worthy of a separate Paper, and at present only one point could be made, namely, that the

ecommended step-back of any upper storey floor, provided, amongst other advantages, eans of access between any sub-divisions of the shed.

With regard to Mr Ordman's remarks, it was true that the cost ratio of 1·6 to 1·8 between ngle- and double-storey sheds did not take into account the cost of extra land required in e case of a single-storey shed, but he had emphasized that the need to conserve space was ne of the most vital factors in any layout. It would be difficult to assess, in many cases, hat the cost of the additional land would be, and one could only base it on all known ctors and decide whether to have a single-, double-, or multi-storey shed.

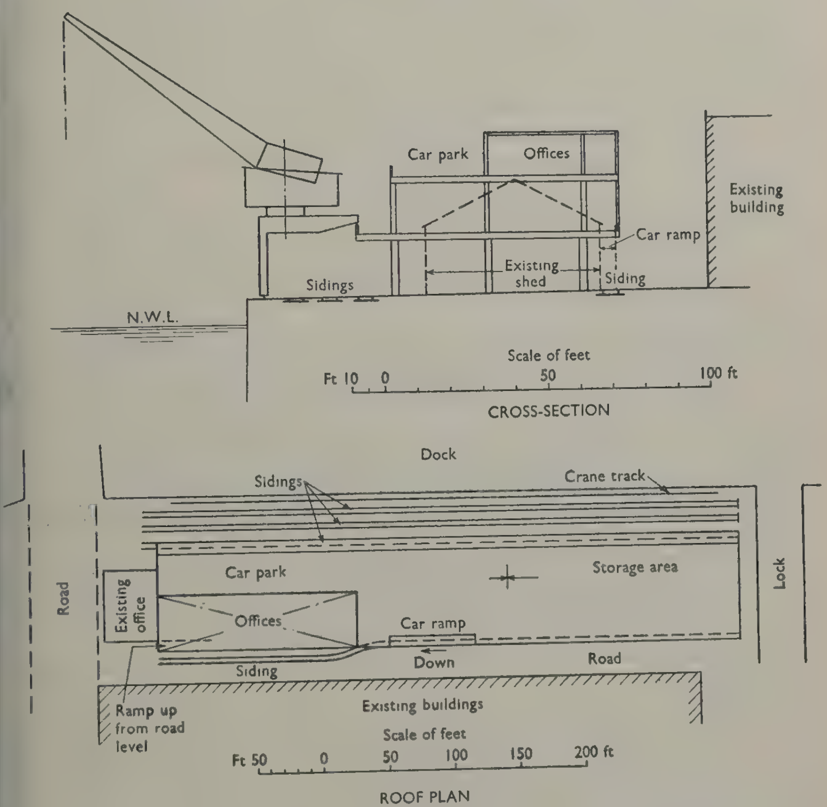


FIG. 38

Mr Sivewright had spoken about drivers preferring the positioning of cranes farther back from the quay edge. That was so, but he felt Mr Sivewright had perhaps based his comments on the fact that on one berth at Avonmouth the front legs of the cranes were only 2 ft 6 in. from the quay edge. That was, unavoidably, too near, and the driving position in the cranes made it awkward for the drivers to obtain good visibility throughout normal operations. Mr Matheson had suggested a figure of 6 ft 6 in. for ordinary conditions, and with a properly designed cab and controls there should be no objections to such a position.

Mr Shire, in reply, agreed that Mr Gamble's cranes were excellent, but Mr Gamble was doing a specialized job, he had very special drivers, and he could therefore afford to buy what was only a "Rolls Royce" crane. He did not think that the Port of London Authority's limited and intermittent bulk-handling requirements warranted such an expenditure.

With regard to the hours between overhauls, he agreed that the figures were very conservative, and since the Paper had been written the times had been extended, but owing to the high incidence of damages, more men had been found to be necessary.

Mr Hammersley had asked about the mobile crane for timber handling. It was basically a standard crane with a special jib; the safe working load was 1 ton at maximum outreach, increasing in the normal manner as the radius decreased, without any special derating.

Diesel-electric conversion of steam cranes had not been examined for the cost was considered to be too great.

The roof transporter was moved from one loophole to the next from the roof; in many instances push buttons at each position would be an advantage, but in the case mentioned the additional expenditure could not be warranted.

The tubular steel handtruck was the first development to meet the Authority's requirements, and improvements would undoubtedly be forthcoming.

Regarding mobile plant inspectors visiting working areas, he did not think that special men were generally necessary in the docks, for the normal supervisor could quickly reach any point when required.

Mr Pannell had asked about flame descaling. Mr Shire's experience was that the method was costly and frequently unsatisfactory; in certain circumstances it involved an unacceptable fire risk.

Mr Sivewright asked if pallet repair costs could be related to tonnage handled or the number of lifts. Unfortunately that valuable information was not available. Most repairs were necessitated by damage which appeared to be an inherent factor in the piece-working system.

With regard to gravity chutes, his experience had been that when fitted they were rarely used, for they were unsatisfactory for handling general cargo.

The reason for the Authority's predominance of d.c. cranes was the lack of a.c. Some a.c. cranes were now being built, and he anticipated that they would be equally, if not more, satisfactory than the d.c.

Mr McBride had asked about wire rope examinations. They were carried out by a separate body of men, irrespective of the type of plant or location, and in general conformed to statutory requirements. Adequate records were maintained, and they were being improved by the introduction of proprietary mechanized systems.

Anti-freeze was used in winter in engine cooling systems, but precautions were taken to prevent pilferage.

The time given for oiling and greasing referred to one crane. The work was undertaken before and after normal working hours, during dock labour's meal breaks, and as and when the plant was not at work for short periods. In London the drivers were not generally kept to one crane, nor did they do any maintenance work.

With regard to tubular jibs, Mr Shire's experience was limited, but no repair difficulties had yet been encountered. He thought that the average welder or boiler maker would readily acquire the technique of working on tubular structures.

Mr Bentham asked about quay-crane maintenance. That work was undertaken by outworking gangs and by the heavy repair shops. The mobile plant was generally treated as a separate requirement.

The control of inspection, annealing, testing, etc., of lifting gear was made effective by an adequate system of records, and by having responsible men in charge of the work, and of the stores in which the gear was kept.

Mr Tooth, in reply, said that from the operating point of view there was a very real link between the various questions asked. Such matters had been raised as the size and type of ships, the design of transit sheds, the size of sheds, the size of doors, the need for

oading platforms, whether there should be gravity chutes, how sheds were going to be used, why the ship always beat the quay (if it did!), whether there should be good access to the shed for mechanical equipment and transport, the economic aspects of mechanization, port layout, and even why coal grabs should be used for sugar which had not yet been refined!

It was well known that there were important developments in palletization in many industries. British Railways were now carrying over 200,000 tons of palletized goods every year and industrial premises were being built, so planned that the dimensions of the sections were multiples of the sizes of the unit loads which the particular organizations normally handled. That was happening not only in the United Kingdom but abroad, and in some countries on the Continent other interesting things were occurring. The Swiss Federal Railways, for instance, owned a large number of 32-in. × 48-in. pallets (he thought about 180,000) and, with 600 industrial concerns in and around Switzerland, had organized a pallet pool. The arrangement was that if a member organization were going to send, for example, 40 tons of goods on 70 pallets, it delivered its 70 pallet loads to the Swiss Railway depot and received 70 similar pallets in exchange. When the loads ultimately left the custody of the Swiss Railways the receiver, also a member of the organization, also gave 70 pallets in exchange.

He mentioned that to show that palletization was no longer an idea, it was something real. Moreover, palletized traffic was not only a land development, it was seeping into the short sea trade routes and there was no doubt whatever that sooner or later it would seep into trans-ocean routes. Such a development could not occur without raising many fundamental questions in the port industry.

The potentialities of the machine were obviously much too important for dock authorities to overlook. They were using the fork-lift truck with a pallet of their own ownership for the time being, but it did not follow that that method would be the one for the future. If palletized cargo became common, port handling methods might be much simplified and the need for a dock-tool pallet would diminish. Certainly transit shed design and the layout of premises generally would be affected; undoubtedly in the future—in 20 or 30 years' time, perhaps—ship design would alter too. In the meantime, however, the policy in London was to introduce mechanical handling methods where possible, employing the dock-tool pallet where suitable.

Correspondence will be published in a later number of the Proceedings.—SEC.

RAILWAY DIVISION MEETING

27 March, 1956

Mr M. G. R. Smith, Member, Chairman of the Division, in the Chair

The following Paper was presented for discussion and, on the motion of t Chairman, the thanks of the Division were accorded to the Author.

Railway Paper No. 61

EARTH MOVEMENT AFFECTING L.T.E. RAILWAY IN DEEP CUTTING EAST OF UXBRIDGE

by

*** John Douglas Watson, M.B.E., B.Sc.(Eng.), M.I.C.E.**

SYNOPSIS

After some introductory remarks, the Author gives a history of the site with an accoun of slips which occurred in 1914 and 1937. The slip which is the subject of this Pap occurred in 1954 and involved a high retaining wall which moved forward 17 in. Imme iate action included strutting the toe of the retaining wall; clay was excavated from behi the retaining wall and the tracks were raised a maximum of 4 ft 6 in. This action w successful in restoring stability. In 1955 more permanent works were put in hand reinstate a public footpath and to support a portion of a public road that was threatene by the slip.

The second part of the Paper consists of a description of the site and laboratory tes carried out and the theoretical arguments advanced in the course of a soil mechan investigation. A trial trench was dug at right-angles to the retaining wall, and a ve large number of samples were taken and tested. At another cross-section pore pressu points were inserted to ascertain the level of the water-table. The laboratory wo included the usual tests to establish the index properties and undrained triaxial compre sion tests on a number of representative core samples at cell pressures of 10, 30, and 6 lb/sq. in. Drained triaxial compression tests were also carried out on two sample From the results of these tests an analysis was made to establish the factor of safety of th bank and wall as reconstructed after the slips. This was done by a new method develope by Mr D. J. Henkel.

The Author concludes that a slip of this nature seldom occurs without warning. Whe it does occur action must be quick and drastic. A soil mechanics investigation may b useful to confirm that the action taken is sufficient and may guide design for permane works.

Introduction

It is generally known that earth movements or slips take place quite frequent and cause much direct and consequential loss to railway, road, and other authoritie The reason for writing a Paper about one particular slip, can, perhaps, be sum marized as follows:—

(1) The description of a particular slip increases professional knowledge an understanding of slips in general.

* The Author is Bridge and Structures Assistant, London Transport Executive.

(2) The slip which is the subject of this Paper was a large one and might have had very serious consequences.
(3) Movement of a high retaining wall took place, involving risk to adjoining residential property as well as to the railway.
(4) The slip was successfully stabilized.
(5) A factor of safety for the bank and retaining wall after restoration was worked out by a new method.

A WALL AND SLOPE ALMOST STABLE

Fifty-four years ago a cutting was made through a gently sloping hill near Uxbridge. typical cross-section is shown in Fig. 1. The maximum height of the retaining all on the south side was 8 ft. There is some evidence that this cutting gave some

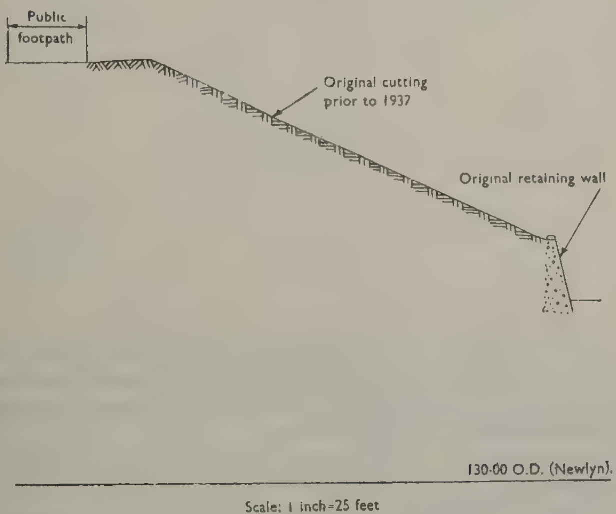


FIG. 1

ouble from time to time from very early days. In 1914 there was a slip on the orth side which stopped traffic. There is a report that the bank was stabilized with mber piles driven by Messrs Peter Lind & Co. Ltd and that the spoil from the slip as piled "funnel high." At several points on the south side hardcore groynes or ounterforts were constructed before 1937. The slope on this side had been planted ith willows. In 1935 when a survey of the London Passenger Transport Board's roperty was being made, several cracks were noticed at the back of Nos 65 and 67 Iontague Road. These cracks were pointed, probably in 1936, and were later found o have opened again. The tar pavement on the public footpath was also found to e cracked in 1937 when more serious trouble took place, in connexion with some ew construction which was then put in hand.

To form the approach for a new station at Uxbridge the cutting had to be widened. he new section, compared with the old, is shown in Fig. 2. A new retaining wall as constructed on the south side with a maximum height of 30 ft above rail level.

While the wall was in the course of construction and the trench for the foundation of the new retaining wall was being excavated, a serious slip occurred on the sout side. A contemporary report exists of this occurrence.

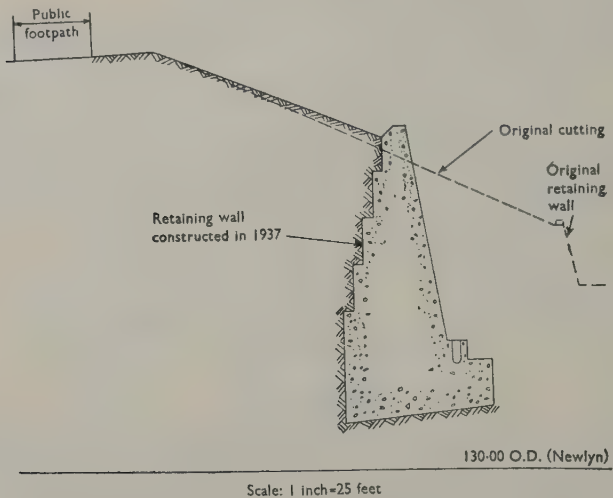


FIG. 2

At 11.40 p.m. on Thursday, 12 August, 1937, the station staff heard a very lou report followed 3 or 4 min later by another report and then a loud crackling noise The following observations were made by the responsible engineering staff when th site was inspected at 4.45 a.m. the next morning.

(*a*) The newly excavated trench was filled with fallen muck and very little c the trench timbering was visible.

(*b*) Blue brick copings had been pushed off the top of the old retaining wall an clay was spewing over.

(*c*) Walings on the low side of the trench had penetrated the muck, in one cas to the extent of 4 ft.

(*d*) Two large fissures had appeared in the top of the bank and the foundation of old houses had been exposed. The fissures were about 2 ft wide and i places 10 ft deep.

(*e*) Several cracks about ½ in. wide and several feet long had appeared in th tar paving on the public footpath at the top of the bank.

(*f*) Brick barrel drains of 9- and 18-in. dia. had been exposed.

(*g*) A concrete mixer, which had been working on the top of the bank, ha fallen into the cavity between the deep fissures.

The weather had been exceptionally hot and dry for some weeks before the in cident and, where the clay was exposed, cracks had appeared. It had bee possible to poke a 2-ft rule 6 in. into some of these, though the depth of the crack probably exceeded 12 in. in some instances.

These observations are illustrated in Figs 3 and 4, and Figs 5 and 6 (facing p. 312.

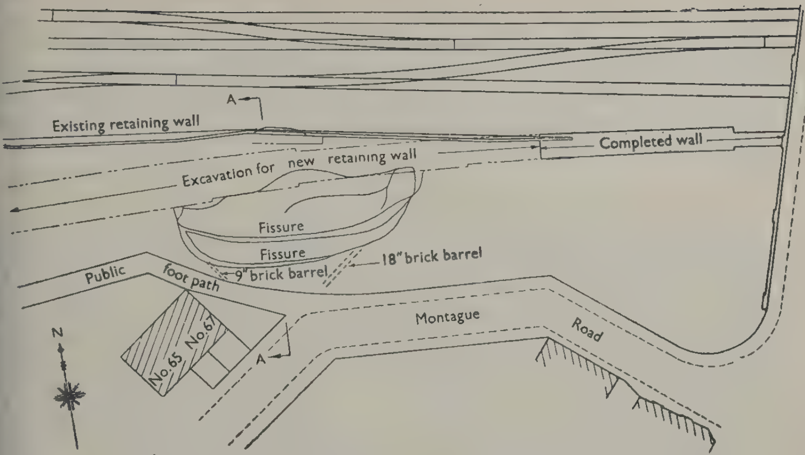


FIG. 3

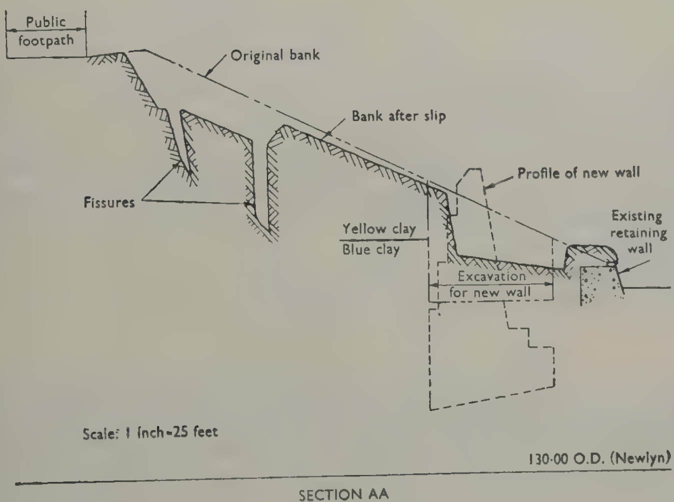


FIG. 4

The following action was taken immediately after the slip. A speed restriction of 5 m.p.h. was imposed on all trains between Park Road Bridge and Uxbridge Station. The deep fissures at the top of the bank were filled with hardcore and loose earth, the reason for this being to afford support for Nos 65 and 67 Montague Road. The work of cleaning out the trench and re-timbering then proceeded night and

day until the trench was safely timbered with struts from the back of the old retaini wall.

On 14 and 15 September, 1937, a small slip occurred at the London end of the si This was attributed at the time to water entering one of the fissures higher up t bank and lubricating the place of rupture. Some timbers showed signs of distre and these were replaced with heavier ones and extra struts. No further troubl with this bank is recorded until 1954.

The commencement of the failure

On 21 September, 1954, information was received from the Urban District Coun of Uxbridge stating that some cracks had occurred in Montague Road and in t footpath parallel to the railway leading towards Uxbridge Station. These crac were inspected on 28 September, 1954, but there appeared to be no connexi between the cracks and any possible slip on railway land. On 10 November, 195 the site was again inspected. Subsidence up to a depth of 4 in. had occurred in t footpath and the Southern Electricity Board's cable, which was buried under t footpath, had developed a fault. A permanent-way ganger, when questioned, stat that a crack in the retaining wall which happened to be opposite the point of ma mum subsidence appeared to be getting worse and he also complained that the tra drain was not functioning properly.

It was clear that a slip of some importance was impending and orders were issu for a survey of the site to be made with cross-sections at 20-ft intervals.

On 22 November, 1954, in response to an urgent call from Uxbridge, the site w again visited. A large cavity had opened in the footpath (Figs 7 and 9) and the was evidence that a major earth movement was in progress (Fig. 8). All the visib phenomena were indicative of the top of a large slip, but corresponding indicatio of the bottom of the slip were not immediately apparent. In the course of intern gation a reply from the permanent-way ganger gave the clue. He stated that was having difficulty in maintaining correct superelevation on the track. Co sideration of this remark led to the conclusion that the tracks were heaving, whi was subsequently confirmed.

It then became clear that the whole slope, including the retaining wall, was on t move and measures were put in hand to record this movement.

Rapid action to improve stability

Measurements of wall movement made it apparent that the slip was menacing t safety of the tracks and that the service to Uxbridge, with its spacious termin facilities, might have to be suspended or curtailed. Orders aiming at the rap restoration of stability were issued accordingly; these instructions provided for:—

(1) Excavation of earth behind the retaining wall at the outside or upper ed of the slip.
(2) Concrete strutting of the toe of the retaining wall.
(3) Stone pitching of the formation with a track raising of 3 ft to 4 ft 6 in.

Excavation behind retaining wall at upper edge of slip

The object of this excavation was to relieve pressure on the retaining wall tendi to make it slide or tilt. Work was started on this from both ends of the slip. the east end a drag-line was brought into a working position just clear of the bend

ontague Road (see Fig. 10, Plate 1). It picked up what it could from this position d at a later stage a bulldozer was employed to cut down the surcharge behind the taining wall and push the spoil within reach of the drag-line. At the west end nother drag-line was manœuvred into a suitable working position and a turning ace for tipping lorries was constructed. Work proceeded from both ends until fficient clay had been removed. Fig. 11 illustrates this work.

oncrete strutting at the toe of the retaining wall

The object of the struts was to stop the retaining wall sliding forward. Eight ruts marked A to H (see Fig. 10, Plate 1 and Fig. 12, Plate 2) were put in during e week-end of 27 and 28 November. Five additional struts, marked I to M, were put on the 1, 2, and 3 December. The method adopted was to dig trenches just below d at right-angles to the tracks. These trenches traversed the space between the oving retaining wall and a low retaining wall opposite, where this existed, or to a ecially provided block of mass concrete. Ready-mixed concrete was brought to ark Road overbridge by lorry and was discharged by means of a chute into rail- ay trucks. The Ready Mixed Concrete Co. made special arrangements for the pply of the concrete, and excavation under the tracks and the placing of the con- ete was done by the London Transport Executive's (L.T.E.) own labour. There as no interruption to the public train service. Fig. 13 illustrates this work.

aising of the track by 3 ft to 4 ft 6 in.

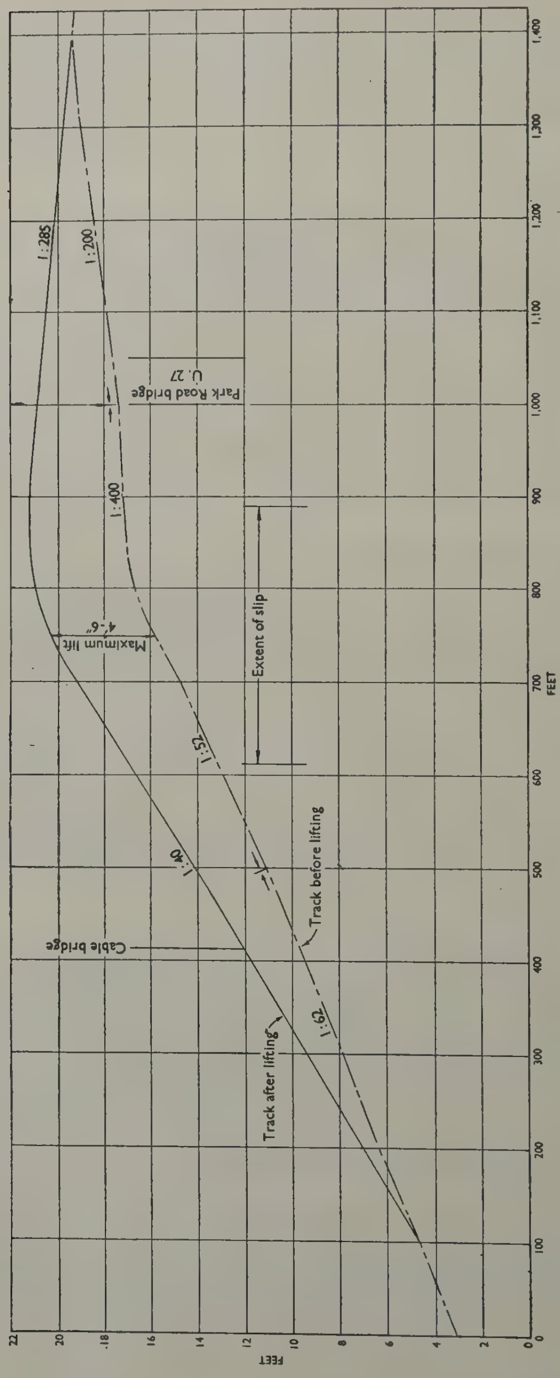
This major work was carried through by the Permanent Way and Signal staff uring the week-end of 3 to 6 December, 1954. Occupation of the line was obtained rom 8.15 p.m. on Friday, 3 December, until 5.00 a.m. on Monday, 6 December. ive hundred permanent-way men, signal and works staff, and lorry drivers worked 12-hour shifts. British Railways gave special facilities to the movement of 400 agon-loads of granite and limestone from the Midlands and Somerset. The track as lifted out in sections by a steam crane and the stone was unloaded by hand from djacent tracks. Signal and power cables were taken from brackets fixed to the re- aining wall, lifted the requisite amount, and relaid in wooden troughs at the new for- ation level. After relaying the track, limestone ballast was unloaded from hopper agons for the final lifting and fettling. A longitudinal section showing this regrading shown in Fig. 14. Much careful planning and careful thought were expended on he execution and supervision of this arduous work.

uccess of action taken between 26 November and 6 December 1954

Figure 15 shows the rate of movement on three selected points on the retaining all plotted against dates. Movement practically ceases on 29th November at oint No. 1. At points Nos 2 and 3 movement ceases on 1st December. These ates can be compared with the dates on which the struts A–H and I–M were put in. During this period about 4,880 cu. yd of earth were removed from behind the re- aining wall and the combined effect of this, the struts, and the raising of the tracks as effective in restoring stability. Fig. 10, Plate 1, Fig. 12, Plate 2, and Fig. 13 facing p. 313) illustrate this phase of the work.

More permanent works and tidying-up

At the end of 1954, the phase of emergency action came to an end. It became pparent that the measures taken had been sufficient to restore equilibrium, and ttention now had to be paid to legal obligations and the rights of adjacent property


1:285
1:200
Park Road bridge
U. 27
1:400
Maximum lift
4'-6"
Excent of slip
1:52
1:40
Track before lifting
Cable bridge
1:62
Track after lifting
FEET
0
2
4
6
8
10
12
14
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18
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22
FEET
0
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FIG. 14

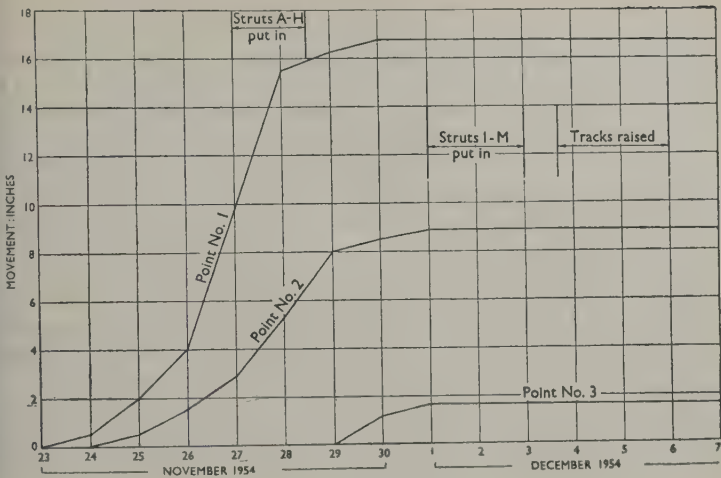

FIG. 15

owners. Fortunately, the Executive's Estate Agent and Rating Surveyor had been able to purchase Nos 65 and 67 Montague Road, the property most seriously affected, and the Uxbridge Council were very helpful in providing housing accommodation for the occupants. A public footpath running at the rear of Nos 67 to 57 Montague Road had had to be closed and an obligation existed to restore it for public use. Finally, the short length of Montague Road which runs parallel to the railway line at the Park Road end of the slip was somewhat lacking in support and works were needed to prevent any extension of the slip in that area. Surveys and schemes for dealing with these matters were put in hand, which are illustrated in Fig. 16, Plate 1, Figs 17 and 18, Plate 2, and Fig. 19 (facing p. 313).

CONFIRMATION BY THEORY OF ACTION TAKEN

When the slip occurred, Soil Mechanics Ltd were asked by London Transport Executive to give an independent opinion of the cause of the failure and the value of proposed remedial measures. It was agreed that a deep trial trench would be excavated so that the ground conditions could be explored. Subsequently Soil Mechanics Ltd were asked to assess the effects of the proposed remedial measures on the stability of the bank.

The trial trench was commenced by direct labour on 10 December and was located about 200 ft west of Park Road bridge; later it was decided to put down borings 30 ft below the base of the steps of the trench to extend the information below the practical depth of trench digging. Eight such hand-auger borings with continuous 4-in.-dia. core sampling were put down. The trial trench and borings were completed on 28 February, 1955. On 1 March, shallow borings were commenced about 50-ft west of the trench to measure pore-water pressures to determine the position of the water-table. Measurements were finally completed on 28 April.

Subsequently stability analyses were carried out to investigate the failure conditions and to examine the proposed scheme for stabilizing the bank.

Geology

The geology of the site is straightforward, there being a thin superficial deposit o topsoil and glacial gravels, up to 5 ft thick, overlying London Clay.

Pre-cutting fill is negligible, although house construction may have left an occas ional rubble-filled shallow excavation. Post-cutting fill has been removed or churne up by recent bulldozing and the rubble and gravel-filled 1937 fissures are the onl clear evidence of the remedial measures then taken. Occasional accumulations o spoil may be found on the gravel in the immediate vicinity of the cutting and in th gardens. The London Clay is roughly divided horizontally into a top brown oxidize layer 10 to 15 ft thick and an underlying blue-grey unoxidized zone, the norma state of affairs. Some vertical displacement due to the various movements wa observed in the trench. The brown clay is rather softer than the blue-grey clay.

Examination of core samples showed that the London Clay at this site is laminate and very highly fissured with local layers and pockets of very hard clay-stone. Th upper weathered brown clay contains pockets of gypsum. The blue-grey un weathered layer contains thin horizontal sand seams, some organic traces, and shell The laminated and fissured structure became more manifest with increasing deptl The consistency of the clay was generally stiff.

The trial trench and borings

During excavation of the trench several slip surfaces were clearly exposed sinc large chunks of clay slipped away when digging near the surfaces, which appeare to consist of very thin moist slide-surfaces with marks of relative movement rathe than softened zones.

As will be seen in Fig. 20, Plate 2, these surfaces were not traced continuously and when prolonged do not join each other, but lie within a zone pointing generall towards the bottom of the wall. The lowest slip surface clearly traced appeared t cut the wall 4 ft above its base.

The change from brown to blue-grey clay in pits Nos 3 and 4 occurred below th slip zone and was at about 158 ft above O.D. (Newlyn). In pits Nos 1 and 2 thi change occurred mainly above the slip zone and was at about 152 O.D. This suggest a total vertical shift due to earth movement since the cutting was made of about 6 f (see Fig. 20, Plate 2).

In pits Nos 3 and 4 a 2-ft-wide fissure, nearly vertical, was encountered lyin approximately parallel to the wall. It was filled with saturated fill consisting o rubble and soft clay from which water entered the trench. The fill probabl extended to a depth of 162 O.D., about 15 ft below the original surface of the bank The natural clay in contact with it was very soft and the base of the fill lay almost in contact with some of the slip planes. This fissure is probably the 1937 fissure which was filled with rubble, referred to above (see Fig. 20, Plate 2).

Large quantities of water were encountered in pit No. 1 at a depth of 144 O.D. about 29 ft below the top of the retaining wall; this water entered through the hard core backing behind the wall and was presumed to originate from the track side During further excavation the water was lowered temporarily about 4 ft. The inver drain level on the track side was again about 144 O.D.

The base of the wall on the inside was located by probing at 135·5 O.D., abou 37 ft below the top of the wall. It was not possible to sample the ground just below the base of the wall because of the water. The dimensions of the wall at the trench section, so far as determined, are given in Fig. 20, Plate 2.

Borings at base of trench

Borings Nos 1 to 8 were put down by hand auger in pairs to a depth of 10 ft below the bottom of the trench in an endeavour to locate further slip planes. The 4-in.-dia. cores were taken continuously and staggered so that no planes should be missed. In pits Nos 1, 2, and 3 the borings were entirely in the blue-grey clay, but in the borings in pit No. 4 the junction of the blue-grey clay and the brown clay was clearly shown. Details of the positions of the borings and samplings are given in Fig. 20, Plate 2. Unfortunately, although each sample was carefully extruded and examined it was not found possible to identify any definite slip surfaces. The very highly fissured nature of the blue-grey clay masked the presence of any slip surfaces. The extruded samples readily broke along these natural fissures. In excavating the trench these fissures did not have the same effect *en masse* because the planes were in fact discovered. An examination of several samples known to be driven across the planes uncovered in the trench failed to locate the planes in the laboratory. However, a softened zone was located in sample No. 125 at 147 O.D. below the base of pit No. 3, indicating that a slip surface probably passed through this point, but this was not confirmed.

Pore-water pressure points

Four borings, numbered 9 to 12, were put down on a section about 50 ft west of the trial trench. All borings were through the London Clay except borehole No. 12, which passed through fill and glacial gravel. Details are given in Fig. 16, Plate 1, and Fig. 21.

A simple pore-water pressure point was installed in each borehole consisting of a porous pot, bedded in sand at the bottom of the borehole, connected to the surface by a length of polythene tubing and sealed above the pot with puddle clay. As each installation was made the pot and tube were filled with water and measurements of water level were carried out by electrical dipping until an equilibrium level was obtained.

The level of the water-table in the London Clay obtained from these piezometers is given in Table 2 and plotted in Fig. 21, which shows a plane water-table inclined at about 25° to the horizontal, falling from 172 O.D. at borehole 12 to 155 O.D. at borehole No. 9 near the retaining wall. While making borehole No. 12 a perched water-table was discovered in the gravel towards the top.

Laboratory tests

Index properties

The natural moisture contents of all samples of the London Clay and the liquid and plastic limits of selected representative samples were determined. The average liquid limit was 86% and the average plastic limit was 24%. The average natural moisture content of the brown clay was 30%, and of the blue-grey clay 26%.

The moisture contents across a slip plane where brown clay overlay blue-grey clay decreased gradually from 30% to 25% over about 3 in. Since these values are about the same as the average values for the two layers there is no apparent softening at the slip in this case. On the other hand, the moisture content across a slip plane entirely in blue-grey clay increased from 25% to 31%, showing an increase of 5% at the slip.

TABLE 2.—PORE-WATER-PRESSURE MEASUREMENTS BY ELECTRICAL DIPPING

Borehole Number		9*	10	11	12
Plan distance	Right angles to wall	1 ft–0 in.	11 ft–7 in.	23 ft–6 in.	36 ft–3 in.
	Parallel to wall	0 ft–0 in.	7 ft–10 in.	8 ft–10 in.	12 ft–10 in.
Reduced ground level: ft		+170·8	+171·3	+177·0	+181·9
Reduced pot level: ft		+151·6	+156·8	+156·7	+171·7
Reduced free water level: ft		†	†	+163·0	+178·9
Pore-water pressure, reduced level: ft	25.3.55	+155·8	+161·3	+166·5	+171·7
	13.4.55	+155·5	+160·8	+166·3	Not taken
	26.4.55	+155·5	+161·3	+166·3	Not taken

* Borehole No. 9 was about 50 ft west of trench
† No water during boring

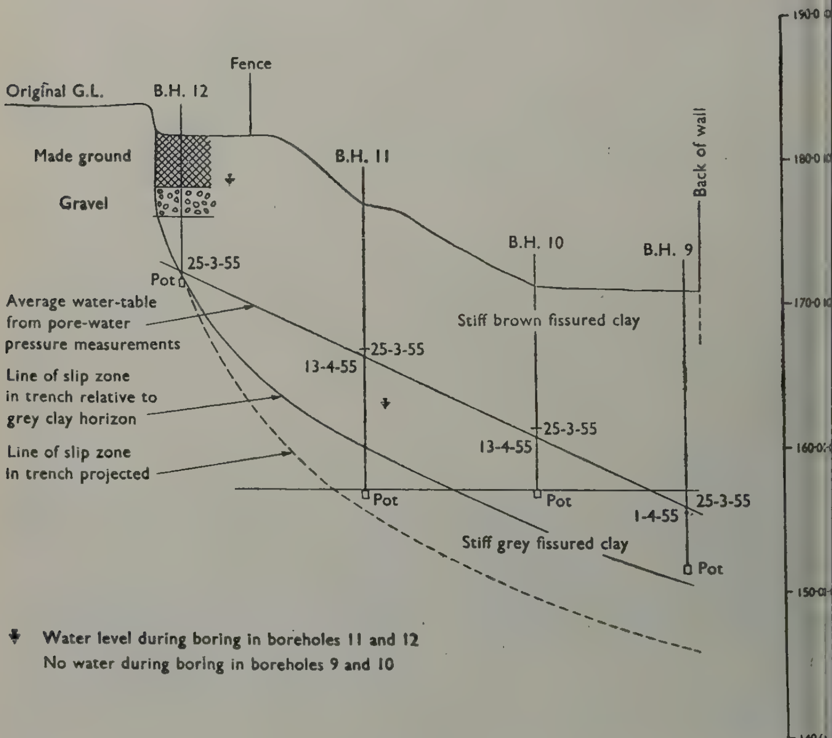

FIG. 21

Fig. 5

Fig. 6

Fig. 7.—View of cavity near 67 Montague Road, showing also the cracks in surface of footpath

Fig. 8.—Cracks in footpath at Uxbridge end of slip

FIG. 9.—TOP OF OLD WELL REVEALED WHEN CAVITY FELL IN
(The pipe was pushed down 22ft when resistance was encountered)

FIG. 11.—GENERAL VIEW, SHOWING CRACK IN RETAINING WALL

Fig. 13.—Work on second lot of concrete struts under tracks

Fig. 19.—General view showing finished slopes at east end of site. Last counterfort under construction on left

Particle-size distribution

Mechanical analyses were carried out on six samples of the London Clay. The average distribution was 0 to 2% of sand, 40% of silt, and 60% of clay.

Shear strength

Undrained triaxial compression tests were carried out on a number of representative core samples generally at cell pressures of 10, 30, and 60 lb/sq. in. The average shear strength of the London Clay clear of the slip zone was 2,230 lb/sq. ft (range, 1,630 to 2,900 lb/sq. ft). The average in the blue-grey clay was rather lower than in the brown clay, probably because of its highly fissured character. The average shear strength of the clay within the slip zone was about 960 lb/sq. ft (range, 220 to 1,580 lb/sq. ft).

Some samples were taken across known slip planes, both vertically and at 45° to the slip, so that the strength along the slip surface could be investigated. In cutting test specimens from samples taken across slip planes uncovered in blue-grey clay the slip plane was no longer visible, probably owing to edge disturbance, and the measured strength therefore may or may not refer to the strength along the slip surface. However, where brown clay was separated from blue-grey clay by a slip plane with no intermediate blue-brown layer (Fig. 20, Plate 2) it was possible to obtain 1½-in.-dia. test specimens with the visible slip plane at the centre. The shear strength at failure for these latter samples averaged 1,510 lb/sq. ft with the slip at 45°, and 1,990 lb/sq. ft with the slip at right-angles to the applied compressive stress.

Drained triaxial compression tests were carried out on one sample of the brown and one sample of the blue-grey London Clay. The results are given in Table 1.

TABLE 1.—CONSOLIDATED DRAINED TRIAXIAL TEST RESULTS FOR PIT NO. 2

Sample No.	Consolidation pressure: lb/sq. in.	Cell pressure: lb/sq. in.	Compressive stress at failure: lb/sq. in.	Correction for filter paper and rubber: lb/sq. in.	Corrected compressive stress at failure	Cohesion (c_d): lb/sq. ft	Drained angle of shearing resistance(ϕ_d): degrees
24 Stiff brown fissured clay (London Clay)	5 15 30	5 15 30	12·2 22·2 39·1	2·0	10·2 20·2 37·1	200	20½
78 Stiff blue-grey fissured clay (London Clay)	5 15 30	5 15 30	11·7 25·8 39·7	2·0	9·7 23·8 37·7	300	20

Note.—Each specimen was consolidated and tested at one pressure.

The apparent cohesion of the clay c_d was about 200 lb/sq. ft and the drained angle of shearing resistance ϕ_d was about 20°. This result confirms the well-known drained shearing characteristics of London Clay, which do not vary much.

One important point when using the results of the drained tests is the accuracy with which the value of c_d, which is about 200 lb/sq. ft, is determined. An inspection of the Mohr circles shows that the value of c_d, the intercept on the shear strength

axis, is very susceptible to the way in which the envelope to the circles is drawn. Since drawing the envelope is to some extent a matter of individual judgement, variations of the value of c_d determined from the Mohr circles may in this instance be inaccurate to the extent of $\pm 50\%$.

Discussion

Experience has shown that with deep excavations in stiff fissured clays, such as London Clay, progressive softening will take place and may continue for many years, reducing the shear strength to a small proportion of the original value. This makes any calculations based purely on the original unsoftened strength quite unreliable. These clays contain a network of hair-cracks or fissures and the shear strength is apparently dependent upon their influence. During an excavation lateral expansion can take place, allowing some of these fissures to open up. They may initiate a softening action. Although such progressive weakening of stiff fissured clay is well known, the phenomenon is not fully understood. It is possible that it is connected with water percolating into fissures which have opened up, but this has not been generally accepted.[1–3]

In the past the design procedure has been to use the $\phi = 0$ total-stress analysis with an estimated value of the softened strength. Success of the $\phi = 0$ analysis depends to a great extent on estimating the probable zone of softening and the softened strength. Since trial pits were used in this investigation these two factors have been investigated to some extent, but it is unlikely that borings would have given the same detail. Using the $\phi = 0$ analysis and assuming a plane slip surface approximating to the slip zone shown in Fig. 20, Plate 2, the softened shear strength for the factor of safety to have been unity at the time of failure is calculated to be about 700 lb/sq. ft. The shear strength of samples taken from the slip zone in the trial trench average 960 lb/sq. ft.

Recent research[4] suggests that the c, ϕ effective-stress analysis, based on effective stress parameters of shear strength, is more fundamental and nearer the truth. The stability of the section, together with the effect on stability of changes of section can be estimated by such analyses with a great deal more certainty. What is required is an accurate knowledge of the position of the water-table, the geometry of the section, and the results of drained triaxial tests. The uncertainty resulting from the estimation of probable values of softened strength does not arise.

Analyses have been carried out by Mr D. J. Henkel with respect to effective stress assuming failure of the retaining wall by forward movement, for the following conditions:—

(1) at the time of failure;
(2) with the slope at the time of failure but with the tracks raised;
and (3) with the soil surcharge reduced behind the wall and the tracks raised as shown in Figs 17 and 18, Plate 2.

In the analyses the effective angle of shearing resistance ϕ was taken as 20° and the position of the water-table as observed at the pore-water pressure points on the site.

The factors of safety given below are taken as the ratio:

$$F = \frac{\text{Wall resistance}}{\text{Active force}}$$

(1) For the conditions which existed at the time of failure the apparent cohesion c was calculated to be 130 lb/sq. ft for the factor of safety to have been unity. The difference between the calculated value of $c = 130$ and the measured value of about 200 lb/sq. ft does not in fact indicate a large difference in shear strength.

(2) Using the calculated value for c of 130 lb/sq. ft, the factor of safety is increased to 1·7 by raising the track level. It is thus clear that the increase of passive resistance resulting from raising the track was the most valuable part of the emergency remedial measures undertaken.

(3) Using the calculated value for c of 130 lb/sq. ft, the factor of safety is increased to 1·9 by raising the tracks, with the section modified according to Figs 17 and 18, Plate 2.

It seems desirable that the factor of safety against forward movement should not be less than 1·5 and therefore the c, ϕ analyses indicate that the reconstruction proposals provide an adequate factor of safety against such a failure if the water-table is kept at its observed level.

It should be noted, however, that a change in the water-table can affect the factor of safety considerably. If the water-table were to rise to the surface of the reconstructed bank the factor of safety would drop from 1·9 to 1·4. Conversely, by lowering the water-table even more than at present the factor of safety would be substantially increased. Because of the critical effect of the water-table and the rather uncertain value of c, it is clearly essential to ensure that the water-table is kept down to its observed level by adequate drainage.

It is clear that this investigation makes a useful contribution to the analysis of problems of retaining walls in London Clay. The trial trench disclosed the position of the failure zone and showed that the failure was of the wedge type, the wall sliding forward. It is extremely improbable that borings would have shown any failure surfaces or have indicated the position of the failure zone so well. Undrained triaxial tests showed an appreciable softening of the clay in the failure zone, but the undrained shear strength was not so low as indicated by the $\phi = 0°$ analysis. Therefore it is unlikely that the $\phi = 0°$ analysis would have yielded any useful and reliable answer in the analysis of the proposed sections. The effective stress analysis, however, was consistent with the failure.

The investigation indicates a most encouraging approach to future problems of retaining wall movement in London Clay. It is suggested that investigations are carried out by means of borings placed primarily across a major section of the movement, and with the following objects:—

(*a*) The determination of the soil succession.

(*b*) Obtaining continuous core samples so that the variations of moisture content can be studied systematically at frequent intervals, and so that a few drained tests on representative samples can be carried out to determine the effective stress parameters.

(*c*) The installation in the borings of pore-water pressure points so that the true water-table can be determined.

From the first signs of failure accurate measurements should be made of the movements of the wall and surrounding ground, including lateral and rotational movements of the wall and ground heave.

It is believed that an investigation can be carried out rapidly on these lines, and

that the present and future stability of a wall can be accurately assessed by means of effective stress analyses.

Conclusions

A major slip does not occur without some warning. Inspection must, therefore, be thorough and include examination of the tops of banks and cuttings. The slightest heaving of the tracks or the cracking or obstruction of manholes and track drains may denote that a slip has started. If these signs at or below track level can be connected with surface indications at the top of the bank or cutting, the existence of a particularly dangerous type of slip can be established.

When such a slip takes place, immediate action must be guided by experience. It must be quick and drastic.

A soil mechanics investigation is useful in confirming that the action taken is sufficient and may guide design for permanent works.

Acknowledgements

The Author is indebted to Mr C. E. Dunton, M.A., M.I.C.E., Chief Civil Engineer, London Transport Executive, for permission to present the Paper; also to Mr L. E. Hawkins, M.B.E., B.Sc.(Eng.), M.I.C.E., Assistant Civil Engineer (Structures) for his help and advice, and to Mr D. V. Singleton who prepared the drawings from which the Figures have been produced.

Thanks are also due to the Directors of Soil Mechanics Ltd for their agreement to the reproduction of matter from their report as part of the Paper.

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The Paper, which was received on 2 December, 1955, is accompanied by eleven photographs and thirteen sheets of drawings, from some of which the half-tone page plates, folding Plates 1 and 2, and the Figures in the text have been prepared.

Discussion

Mr C. E. Dunton (Chief Civil Engineer, London Transport Executive) found the Paper interesting because it described a problem with which all engineers had grappled over many years, aided by a rather tenuous theory. The theory of London Clay had changed from time to time, and had never been very reliable.

A slip of a high retaining wall in an awkward place, such as that at Uxbridge, and which was complicated by a previous case history, afforded a good opportunity to couple

EARTH MOVEMENT AFFECTING L.T.E. RAILWAY IN DEEP CUTTING EAST OF UXBRIDGE

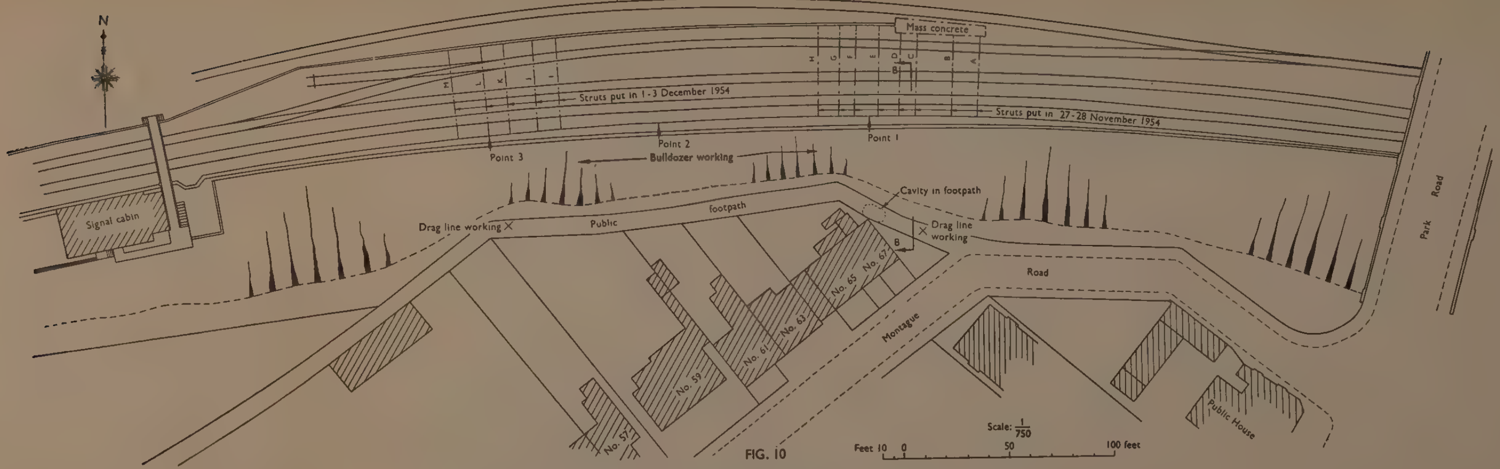

FIG. 10

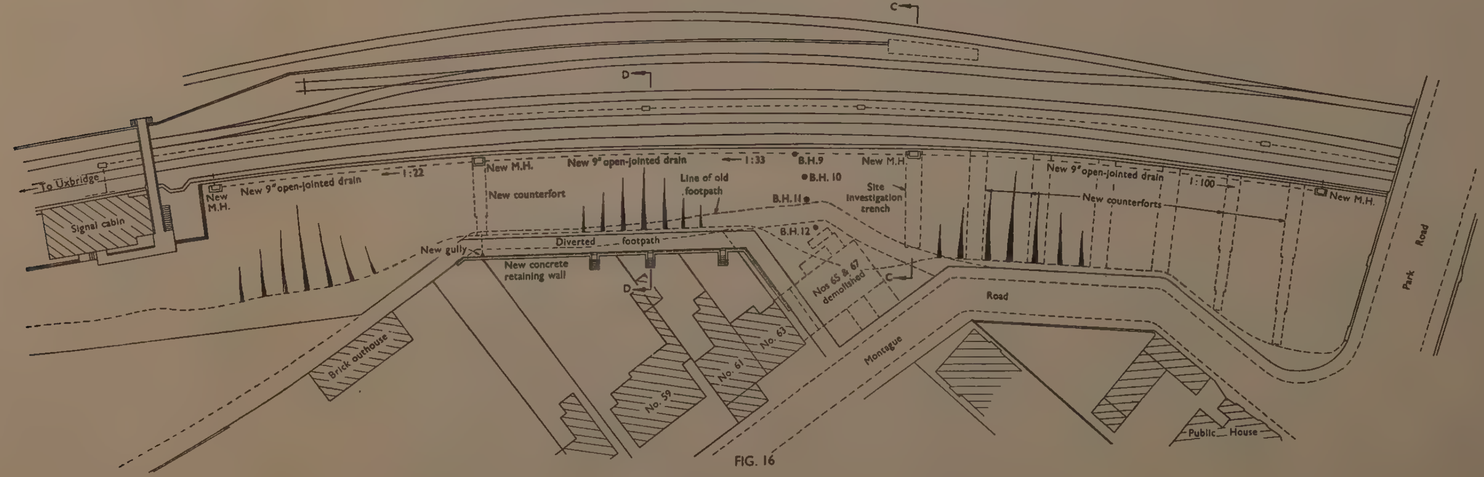

FIG. 16

The Institution of Civil Engineers. Proceedings, Part II, October 1956

J. D. WATSON

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PLATE 2
L.T.E. EMBANKMENT SLIP
AT UXBRIDGE

EARTH MOVEMENT AFFECTING L.T.E. RAILWAY IN DEEP CUTTING EAST OF UXBRIDGE

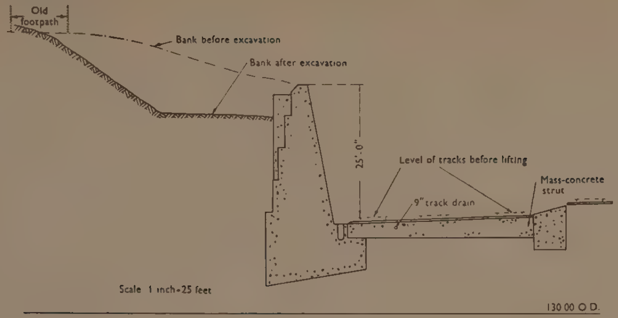

FIG. 12.—SECTION BB

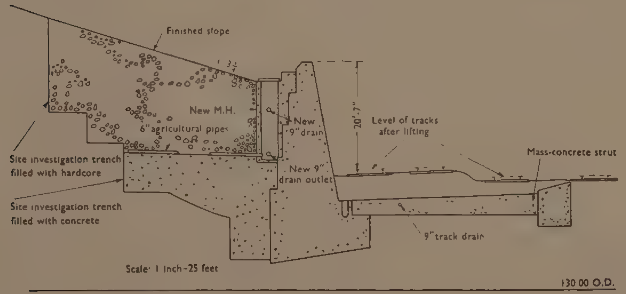

FIG. 17.—SECTION CC

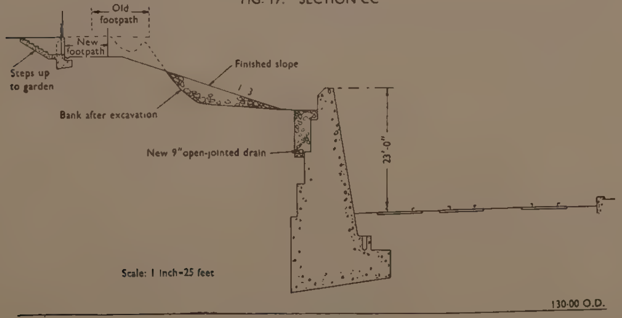

FIG. 18.—SECTION DD

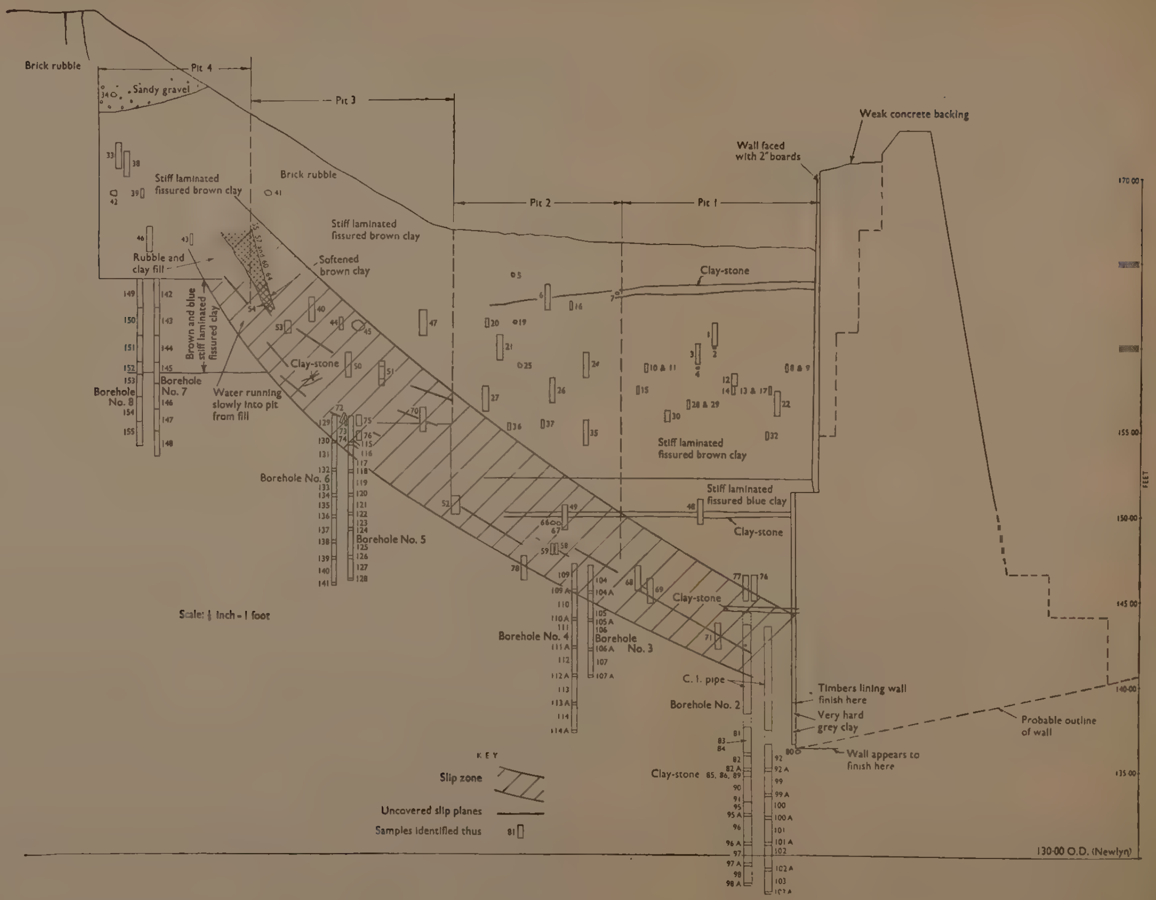

FIG. 20

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together what was new in the knowledge of the behaviour of London Clay (as obtained through soil mechanics) with the practical measures which had had to be taken very quickly to save the wall. It seemed to him that even if theoretical investigations could not help towards taking a decision—which had to be taken literally on the spot, within hours—at least they ought to be able to help in showing how far the emergency measures had been successful.

It had been important to discover what was the factor of safety of the remedial works. It had seemed clear that when the wall was moving there was a factor of safety of unity, or a little less. What was it after the money had been spent? It would not have been satisfactory to follow the normal practice—applied to the earlier slip on the Uxbridge site—hoping that the movement would not recur. It was known that there had been further trouble and that the conditions had not been fully understood or remedied. So he had decided what to do on a practical engineering basis as quickly as possible, but, simultaneously with the carrying out of those works as an emergency operation to save the wall, he had arranged to take full advantage of whatever soil mechanics could offer towards an understanding of what had happened and an evaluation of the remedial measures taken.

It was, of course, unfortunate that the theory could be applied only after a good deal of ground sampling. Trenches had had to be dug to get the full information, since the borehole technique appeared to be somewhat disappointing in application to the fissured clay. They had not been able to ascertain whether or not there were slip planes in the samples from the boreholes; the clay had been so very disturbed that it was very difficult to tell where the slip zone ceased. Mr Dunton had had a fairly clear conviction that they would find slip planes below the footing of the wall, but boreholes at that depth had been in water and the conclusions from the samples had been negative. It had seemed that the trench method was the only really reliable way of determining exactly where the slip planes had occurred. Nevertheless, it was felt that something of value had been learned from the investigation.

The ultimate questions were: what was the factor of safety after the remedial works, and which of the remedial works had been the most effectual—the strutting, the raising of the track, or the cutting back of the slope? The Chairman had observed that the putting in of the struts had produced a dramatic change in that the catastrophic movement had been arrested. That conclusion was not confirmed by the theoretical investigation. The small retaining wall on the other side, used as an abutment for the struts, whilst it might resist the movement for a short time, would he thought, have been affected by the continued pressure and after a time the movement would have been resumed. In any case, the conclusion drawn from theory was that the most effective measure had been the raising of the track. Of course, that measure depended on the fundamental geometry of the system. It reduced the effective height of the wall and the advantage was very clear.

Whilst he thought that the best measures had been adopted, it had not been an easy operation to plan or carry out. For example, care had had to be exercised to avoid burying the large number of cables and signal apparatus on the face of the wall and the drain at its toe. The cables had been freed from their runs and put in a movable troughing so that they could be raised as the track was lifted. The organization of the work programme had had to allow for the transport of stone from the Midlands, the working of a large number of works trains through intensive passenger traffic to the site, and the rapid tipping of the stone. Mr Dunton congratulated the Author and all the staff concerned with the incident on the expedition with which the work had been done.

One of the diagrams displayed by the Author when introducing the Paper had given a proper sense of the urgency. It showed how the slight movement of the wall during the first one or two days could develop, on the third or fourth day, into catastrophic movement. It was obvious that action was required within a matter of hours. All concerned had been infused with that sense of urgency without which the movement would not have been checked. Apart from those immediately concerned, many others had

helped—the suppliers of the stone, the Regions of British Railways, who had given special wagons and special paths for the trains.

The first moral to be drawn from the Uxbridge slip was the one to which he had already referred—the need to understand the phenomenon, the need for soil mechanics to do everything possible to interpret those failures which occurred from time to time. The second moral was that, to avert serious damage and loss of facilities in such circumstances, the utmost speed was essential.

Dr H. Q. Golder (Director, Soil Mechanics Limited) said that when Soil Mechanics Limited had been asked to help the engineers of the London Transport Executive, they had been given an entirely free hand. They had been told that what was wanted was an independent opinion both on what had happened and why it had happened and on what was being done about it.

His first emotion had been one of gratification at having been asked to do this on what was quite an important job. He had then visited the site, and his second emotion had been, "What a lovely slip!" He had, of course, felt it tactful not to reveal that emotion in front of the engineers! His third reaction had been one of helplessness. What else could one do but what they were doing? All the measures based on the geometry of the problem which were the obvious and right ones were being rapidly undertaken, and there was little else that one could suggest, except to investigate the happening in detail and learn something for future occasions.

Fourthly, he had had a feeling of admiration for the energy, courage and sense with which the problem was being tackled. There had been a terrific sense of vigour in the way in which the work was being carried out, with things really humming. The work had been going on very energetically, and he thought that those three factors—energy, courage to think big and do everything straight away, and commonsense, added up to sound engineering.

One thing that Soil Mechanics had been able to suggest was that they should approach Prof. Skempton and his colleagues to see whether they could help, particularly as they were working on a study of these happenings and would no doubt be pleased to be called in to an incident so near home. Mr Henkel had been most happy to come out and give his advice. In carrying out an analysis, Mr Henkel had made many useful suggestions and asked for certain information, which they had done their best to supply. Mr Henkel had then produced an analysis which was a major step forward in the understanding of these problems.

He thought there were three results of that co-operation. The first was that probably the engineer felt much happier about his wall. Secondly, there would be a very useful guide for future occasions. Thirdly, he thought that the co-operation had increased enormously the value of Mr Henkel's research work, for Mr Henkel had been able to apply his work to an actual problem and give an answer.

From p. 315, it would have been seen that what the research had done was to show the increasing factor of safety if the water-table dropped, or the reduction in the factor of safety if the water-table rose. All engineers dealing with banks knew that the important rule was drainage and more drainage, and what the research had done, as was so often the case, was simply to explain the rule of thumb.

There were three questions which he thought should be asked. First, why had the slip happened then? There had been two slips on this site. On p. 306 the first one was referred to; it had taken place during dry weather, but digging had been going on, and that was possibly a sufficient answer as to why it had happened then. The second slip had taken place in November; presumably, as usual, it had been wet then; and the slip had been very gradual. He thought that the most outstanding thing about it was that it had been gradual to start with; as the Author had pointed out, it had speeded up pretty rapidly until something was done about it.

The second question was whether the slip could have been predicted, bearing in mind the work which had been done? If that had been known beforehand, could the slip have been predicted, and how?

Thirdly, assuming that it could have been predicted, what difference would that have ıade to the measures which were taken? He did not know, but he thought that probably would have made very little difference.

Finally, he showed two slides. The first showed a picture of the trench that had been ug. It would be agreed that it was a pretty big excavation. When the soil mechanics eople had said that they would like a trench in order to reveal a lot more than the oreholes, the engineers had gone straight ahead and put down a really big excavation. here had been no niggling about what it was going to cost.

The second slide showed a slip surface. Some people might not have seen a slip urface, and possibly did not believe that slip surfaces existed. One could see the cratches on the material where the clay had slipped down. It was quite polished and uite shiny.

Mr H. E. G. Stripp (Borough Engineer, Uxbridge) counted himself privileged, as general practitioner in the sphere of civil and municipal engineering, to have been in at he birth of the slip and to have acted in some capacity as an unofficial watchdog for ondon Transport Executive in observing for them the cracks which had appeared on he footpath at the top and which later had led to the much greater movement of the wall.

Three remedial measures had been taken to avert even worse damage; the removal of he load from the top of the wall, the insertion of the concrete struts, and the weighting f the toe of the wall by raising the track. He thought the most interesting to be the nsertion of the concrete struts. What was the basis for their design? There was urely some basis on which the struts had been designed with regard to size. Mr Dunton ad already given the reason for raising the track after it appeared that the struts had lready done the work, but Mr Stripp imagined that there was yet another reason—amely, that there was practically no clearance between the rolling stock and the wall ı its new position.

What was the effect on the wall (it having moved) of the removal of the weight of the verburden? To what extent had it really contributed towards slowing down the novement of the wall?

He had been particularly interested in the comparison between the practical solution vhich had been arrived at on the spot, based very much, he thought, on wedge failure, nd the theoretical approach by the soil mechanics research people. He could confirm hat Dr Golder had said; he had never seen such a clear glass-like slip-plane surface.

Could the Author say if the wall, after slipping, had been in the same vertical plane s before, or had there been any obvious tendency to rotate or overturn?

There was a brief reference on p. 310 to gypsum having been discovered in the upper eathered brown clay. Experience in dealing with London Clay, and particularly with he gypsum crystals which were found in varying concentrations, had shown the serious ffect which that could have on concrete. Was there any record of sulphate attack on he wall? He had noticed none himself, but no doubt the Author had had many more pportunities of examination of that aspect.

To what extent did the Author think that the slip might have been influenced by the uperimposed weight of the two buildings, Nos 65 and 67 Montague Road (later emolished)? If that loading had contributed to the slip, then some thought should be iven to the precautions which would have to be taken in future by those who were oncerned with property near (but off) railway property in regard to the design of new uildings close to cuttings.

The incident had taught him the importance of making continuous accurate measure-nents as a slip progressed. It was only as a result of those accurate measurements that t had been possible to show the probable effect of each of the remedial measures taken. Ie thought that a further lesson to be learned from the incident was that the design nd possibly the maintenance of structures required more care than they had been given n the past and that regular inspection of such structures as retaining walls, culverts, and he like should be made. The railway organization undertook regular inspections of the

tracks, but Mr Stripp believed that many who designed retaining walls and built them in remote places never saw them again.

Finally, as the built-up areas of Britain were expanding, so were the public services and much municipal engineering work was being done very close to railway property. At the same time, railway engineers were widening tracks and doing a lot of work very close to municipal engineers' works; co-operation was becoming more and more necessary.

Mr Stripp thanked the Author for permitting him and his staff to have access to the work during construction, from which they had learnt a great deal.

Mr D. J. Henkel (Lecturer in Civil Engineering, Imperial College) said he was grateful to Mr Watson for putting on record the details of the wall failure at Uxbridge, particularly since the pore-water pressures in the ground had been measured soon after the slip.

He wished first of all to correct an impression, given in the Paper, that the effective-stress method was something new developed by himself. He thought it was fairer to say that it was only the application of effective-stress methods to the long-term stability problems in stiff fissured clays and was part of joint research work being carried out at the Imperial College.

In the effective-stress method it was necessary to know the pore pressures in the ground and also to use the shear-strength properties of the soil expressed in terms of effective stresses.

From the results of a large number of drained triaxial tests carried out on samples of London Clay it appeared that the laboratory values for the angle of shearing resistance ϕ' and cohesion c' in terms of effective stresses, were 20° and 250 lb/sq. ft respectively. If, however, those values were used in the analysis of known long-term failures a factor of safety greater than unity was always obtained. However, the analyses of the failures of natural slopes suggested that on a geological time scale the cohesion intercept became zero. Bearing that in mind, the wall failures in London Clay had been analysed in such a way that using $\phi' = 20°$ the value of c' for equilibrium was found.

Fig. 22 showed in principle the method of analysis used for the wall at failure. By considering a number of possible sliding surfaces the maximum active force due to the clay behind the wall had been found and the active pressure diagram showed those maximum forces for $c' = 0$ and $c' = 200$ lb/sq. ft. By a similar process, the minimum resistance of the wall combined with the passive wedge at the toe had been calculated and again the diagram showed the results for $c' = 0$ and $c' = 200$ lb/sq. ft. By a process of interpolation the value of c' which just satisfied static equilibrium had been found to be 105 lb/sq. ft. As could be seen, the pore-pressure forces designated by U were fairly large and unless field measurements of pore pressure were made at the time of failure a major uncertainty was introduced into the calculations.

In order that that value of 105 lb/sq. ft might be seen in its true perspective it had to be compared with the results obtained from the calculations made for some other wall failures. In Fig. 23 the time which elapsed between construction and failure was plotted against the calculated cohesion intercept at failure. Although only 17 years had passed between the construction and failure of the Uxbridge wall the clay at the site had been stressed, although less severely, since the original cutting had been made in 1902. In view of that history the Uxbridge point had been tentatively plotted against the time of 29 years, one-third of the life of the original cutting having been added to the 17 years.

Although some of the points on the figure might have to be altered slightly as additional data became available, there was a definite trend for the lower values of c' to be found with the greater time intervals and that tied in with the fact that on a geological time scale c' tended towards zero. There was, however, another complication in that the walls often had very different heights and in consequence the depths to the slip planes varied considerably. Against each of the points in the figure the average depth to the slip plane had been recorded. And it could be seen that in addition to the time effect the lower values of c' were associated with smaller average depths to the slip surface. More data would be necessary before that depth effect could be isolated.

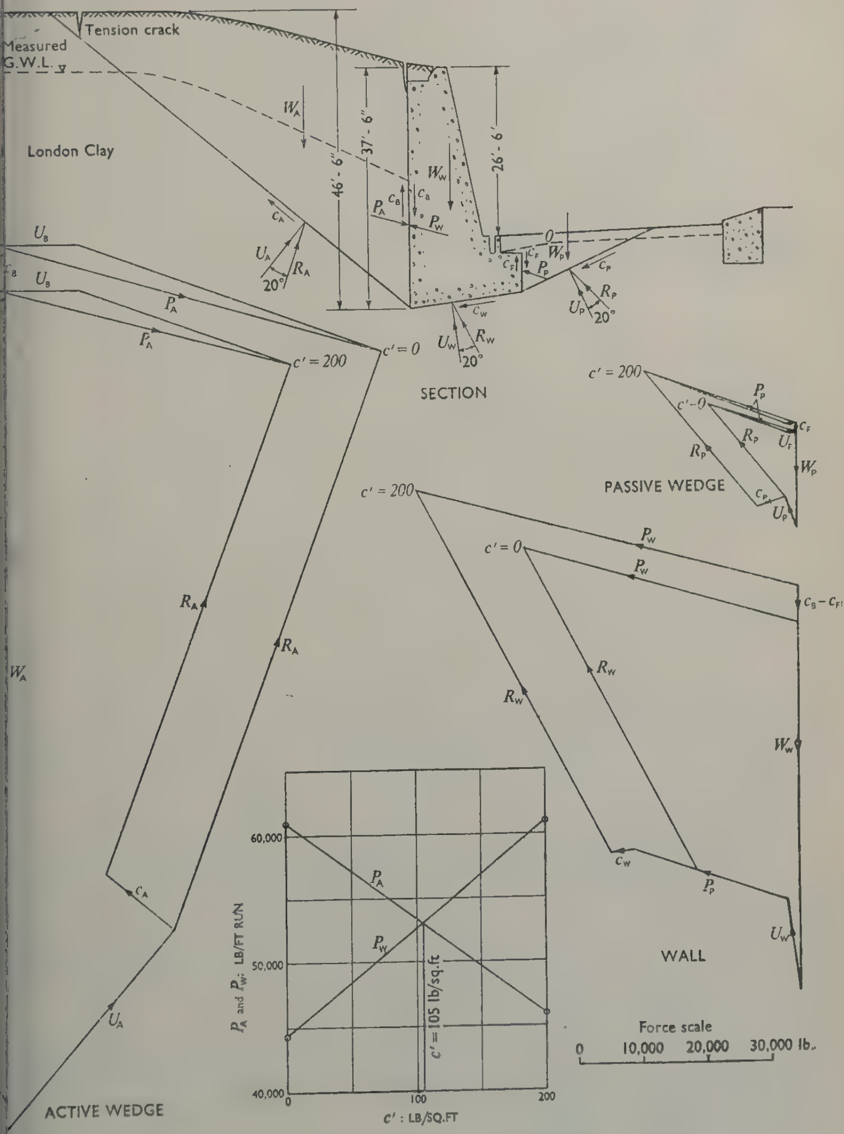


FIG. 22.—EFFECTIVE STRESS ANALYSIS OF WALL FAILURE. $\phi' = 20°$

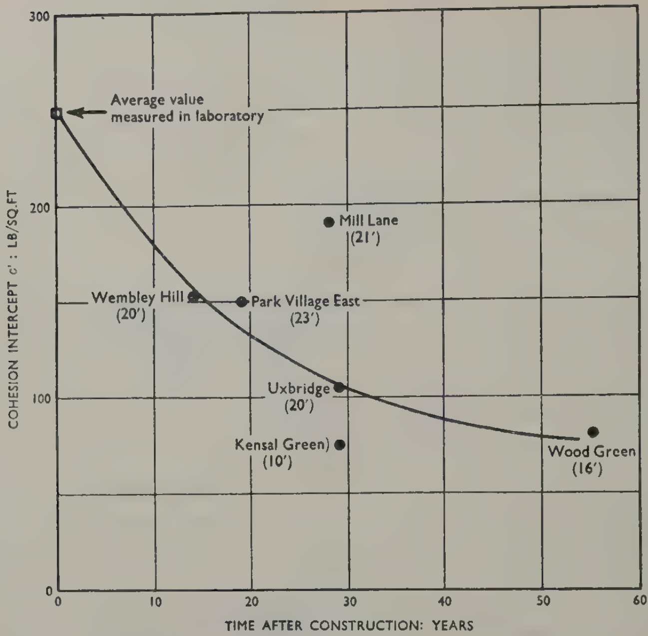


FIG. 23.—DECREASE IN "COHESION" INTERCEPT c' WITH TIME IN LONDON CLAY ($\phi'=20°$). DATA FROM RETAINING WALL FAILURES

However, in spite of the uncertainty about the precise value of c' it was useful to examine the errors involved in using the limiting values of $c' = 0$ and $c' = 250$ lb/sq. ft. Calculations had been made for the Uxbridge wall, and for $c' = 0$ the factor of safety was 0·84, whilst for $c' = 250$ lb/sq. ft the factor of safety was 1·24. That relatively small range of factor of safety showed the advantage of the effective stress method over the $\phi = 0$ method, which, in a number of published cases where it had been used, gave theoretical shear strengths for failure of only one-third of the measured strengths.

In practice it was prudent to use the lower limiting condition of $c' = 0$, and to be satisfied with a low factor of safety. That was particularly important in the design of remedial measures after a slip, since the large shearing deformations associated with failure might substantially reduce the value of the cohesion intercept. When $c' = 0$ was used for the Uxbridge wall, with all the remedial measures taken into account, a factor of safety of about 1·3 was obtained and, provided the pore pressures in the ground did not increase above those measured, the wall should remain stable.

In view of the great importance of the pore pressures in controlling stability it would be useful if pore-pressure points in any slope which had given trouble could be left accessible so that periodic readings could be taken and warning given of any dangerous increases in the pore pressures following exceptionally wet periods or if the efficiency of drainage measures were reduced.

The extent of the softening which could take place in slopes in fissured clays had not often been recorded and Fig. 24 indicated the moisture content distribution in sample 12 from borehole No. 5, shown in Fig. 20 of the Paper. The sample had a soft zone about ¼ in. thick running through it and the water contents at a number of points were measured up to 4 in. each side of the soft zone. From a peak value of 36% the water

ontent very rapidly dropped to the value of 28%, which was typical for undisturbed ondon Clay at that depth of about 30 ft below ground surface. The fact that the oftened zones were often so thin made it very difficult to pick them up in boreholes and o indication of the incipient weakness might be revealed in an ordinary investigation.

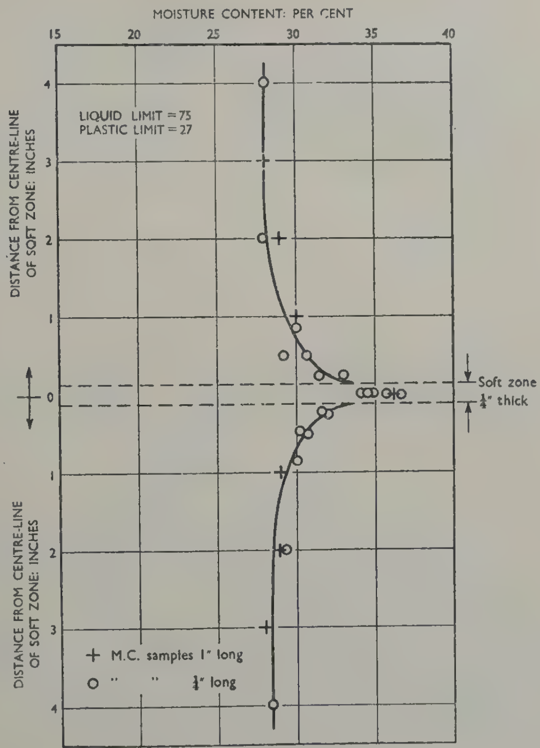


FIG. 24.—MOISTURE-CONTENT VARIATION IN VICINITY OF THIN SOFT FAILURE ZONE IN BLUE LONDON CLAY 30 FT BELOW SURFACE AT UXBRIDGE

There was insufficient time to go into the possible mechanism of softening but it was elieved to be associated with the dilatancy accompanying local shearing strains which ould take place in fissured clay slopes.

Mr D. A. Brown (a Senior Assistant, Sir Murdoch MacDonald and Partners, onsulting Engineers) said that the Uxbridge branch had been opened to traffic in 1904, nd from what the Author of the Paper had said it would be realized that there had been onsiderable trouble with the slopes. The slope on the north side of the old station had een burnt; burning of clay slopes was a method of changing the characteristics of the lay from a cohesive to a granular brick-like material. The method had now fallen into isuse, probably for two reasons—the high price of coal, and the difficulty of burning at epths of more than a yard or so below surface.

Referring to the failure in 1937, the old retaining wall, shown in Figs 1, 2, 3, and 4, ad been found to have concrete buttresses at the back. They were of various sizes and,

according to Mr Brown's recollection, were about 4 ft square in plan. The buttresses had their tops level with the top of the concrete wall. Amongst the old records had been found two drawings of the old wall, both different and neither showing the buttresses. The presence of the much thicker section of the old wall, near section AA in Fig. 3, had therefore been entirely unsuspected. Owing to the steep angle of the old clay slope and the difference in level between the two sides of the trench, the upper walings on the high side of the trench had been supported by raking struts whose lower ends rested on timber footblocks sunk into the berm at the low side of the trench. Reference to Fig. 3 would show that the footblocks were resting on a very thin layer of clay on top of the unsuspected thickening of the old wall. His view was that the dry and hot weather before the slip had caused the clay supporting the footblocks to crack and lose its cohesion, thus letting the rakers down. The earth had fallen on to the quite substantial timbering and knocked it all out. Hardly any timbering had been visible the next day.

The photograph shown in Fig. 5 had been taken a few days afterwards, when reclamation work had started.

He had been very surprised to hear of the movement of the wall, and had to assume that the curvature in plan had contributed to its stability, but he would be interested to hear the Author's views on how the wall should be designed in the light of recent investigations.

Mr D. L. Bartlett (Soil Mechanics Laboratory, British Railways, Western Region) said that the Paper clearly demonstrated the logic, so far as fissured clays were concerned, of carrying out drained triaxial tests and subsequently analysing a slip with respect to effective stresses. Any other type of analysis in that sort of material would certainly produce an incorrect solution, both with respect to factor of safety if the slip surface was known and position of the slip surface if it was unknown.

There existed in the method, however, at least one disadvantage which had not been mentioned, namely, that of the time involved. Where frequent slips had to be investigated by a laboratory (and he was thinking particularly of the Railway Soil Laboratory), and where such slips were invariably affecting the running lines in some way or another, it was essential that a quick answer be obtained so that temporary, if not permanent, remedial measures could be taken immediately.

The alternative was that remedial measures would have to be applied without any quantitative idea of their efficiency, as had in fact been done at Uxbridge.

To the non-soil mechanics engineer the question of time might not seem important so far as comparing one triaxial test with another was concerned, but the fact that a drained test might take about 300 times longer to perform than an undrained test, i.e., comparing 48 hours with 10 min, could not be ignored, especially when, as invariably happened, particularly in embankments, soil conditions were heterogeneous and the drained shear parameters had to be obtained for each different stratum. Furthermore, pore pressures in the bank or cutting had also to be established, a procedure which, using the type of equipment described by the Author, would take at least 3 weeks.

Apart from the time involved in making a drained test it could not be guaranteed that the critical plane arrived at by analysis coincided with the actual failure plane existent on site. The only alternative which presented itself was to locate the slip plane by direct means. The Author had in fact done so by having a trench excavated, but in the general run of jobs that was not economical or practicable.

A number of methods of locating slip surfaces existed, but they all suffered from a number of disadvantages which Mr Bartlett felt had been overcome in the method devised by the Western Region Laboratory. Its operation, of course, applied only to active slips, but as railway engineers knew and as the Author had pointed out, practically all slips showed some signs of movement before failure actually occurred.

The method consisted of inserting into the site of a suspected slip a number of lengths of polythene or alkathene tubing of the same type as described by the Author in connexion with pore-pressure measurements. The insertion required no boreholes or complicated equipment, and an average rate of placing in a firm clay was six 20-ft lengths

tubing in about 3 hours. The tubing having been installed with some initial degree of ignment—that alignment being checked by plumbing with a mandrel—the site was ft for some convenient period; it was then revisited and the initial alignment checked, sing the same mandrel as before. If movement had occurred, then the alkathene ıbing would be deformed, and the point of deformation would be detected. The time hich must be allowed to elapse before replumbing the alkathene was obviously a function the rapidity of movement of the slip.

The merits of that direct location of the slip plane revealed themselves particularly hen the soil conditions were complex and the analysis complicated. The only major sadvantage which existed with that method was that in its present form the location multiple slip planes was not possible. However, some form of flexible mandrel was eing developed which it was hoped would overcome that disadvantage.

Mr F. L. Cassel (Chief Soil Engineer, Le Grand, Sutcliff & Gell Ltd) said that it was ldom possible to determine the exact location of a slip plane from borehole samples. was to be regretted, therefore, that it had not been possible for the trenches excavated Uxbridge to be taken deeper to where there might be found a circular slip. The aper assumed that the slip had a wedge shape—very rare in London Clay, where nearly l known slips had a more or less circular shape. So far as he could gather from the aper, sample No. 125, to which Mr Henkel had referred specifically, had been found about ft below the zone of the wedge, i.e., at a place where one would have expected a circular ip to have occurred. The other samples in the boreholes had not shown similar signs the same level, and there was no certainty that the slip had been really wedge-shaped. bviously there was a very wide zone of slipping, as shown by the numerous smaller ip planes indicated in Fig. 20, Plate 2.

The Paper showed a very distinct preference for drained shear test results as compared ith the $\phi = 0$ theory, and whilst he agreed that it was much more rational and probably onformed more with the real facts, in practical work it would very seldom be possible to ake use of it, as Mr Bartlett had pointed out, because of the greater duration required r drained tests and the high costs involved. According to the Paper, the main reason hy the normal form of analysis had been turned down was that the mean shear strength the samples in the failure zone had been found to be about 960 lb/sq. ft, whilst for a ctor of safety of 1 it could not have been more than 700 lb/sq. ft. How had that mean ress value been found? A large number of samples which had been tested had varied in rength from 200 to 1,500 lb/sq. ft, giving a mean value of 960 lb/sq. ft. He supposed at among those samples there had been quite a number which were not softened at all. a large zone of slipping there would always be large lumps of clay which were not oftened. The softened zones were widely scattered and amongst them were lumps which ad undisturbed, or practically undisturbed clay which was not very much softened, and e method of finding the mean figure in the failure zone was, therefore, questionable. ad only a few of those undisturbed and not softened samples been omitted when trying determine an average value of shear strength in the zone of slipping, one would find factor of safety differing little from unity.

It was stated that in the drained tests a correction of 2 lb/sq. in. had been made for ıbber and filter paper. When the samples had been tested in undrained tests, had here been also a correction made of, say, 1 lb/sq. in. for rubber, because that would ring the factor of safety down from 1·3 to 1·13?

He stressed that because a few days previously he had read that Mr Toms, when vestigating the Medina Wharf slip, had made his calculations both ways, with the $\phi = 0$ nalysis and with the drained shear-test analysis, and had recorded that his results were ractically the same with regard to the factor of safety. Mr Cassel believed that in the arly Swedish slip reports, which had been recorded recently in *Géotechnique* there had een similarities of results whether taking values of C (and $\phi = 0$) or drained shear-test esults (i.e., ϕ and C).

He believed that everybody who frequently had to deal with such matters would agree hat in practice one would usually have to stick to the $\phi = 0$ theory, which had done such

good service. It was important to know, however, whether one committed a very seriou error.

The three questions posed by Dr Golder had also occurred to Mr Cassel. First, wha was the reason for the slip? There could be little doubt that the reason for it was th perched water-table in the gravel top and the water-filled gravel of the old slip crack which had permanently given entry to water from the perched water-table. He though that had been proved by the measurement of pore pressure in the slope later on. Secondl could it have been predicted? Knowledge of the water-table would have assisted bu normally one would not look for that.

Mr Cassel understood that the retaining wall had shown cracks for a long time. Wa that so? Since when had it been known that the retaining wall had very serious crack and had they been observed? If so, the conclusion could be drawn that there was wat behind the wall and drainage would be required. He had had a very similar case a fe years ago of a retaining wall in the London area which had failed seriously, and it ha been observed that old cracks had started opening again. Some borings had been pu down at various points, and a high water-table had been found. The wall had n actually moved but future failure was suspected, so 12-in. boreholes had been put dow and filled with gravel. To provide drainage outlet, smaller holes had been diamon drilled backwards from the toe of the wall to the bottoms of the boreholes. It had bee a difficult task to ensure the registration and great credit was due to the foreman who ha completed the drilling accurately. The result was a permanent drainage.

Mr D. J. Palmer (Engineer, Soil Mechanics Ltd) said that the investigation ha afforded a comparison between the classical theories of failure of retaining walls an field observations. It had also allowed some consolidation of Mr Henkel's approac He thought that Mr Henkel was correct in saying that his theory was not new; it ha first been put forward by Coulomb; but Mr Henkel was being a little modest in estimatin his contribution to it.

Had the Uxbridge slip generally borne out the Coulomb assumption of the plane slidin surface? The slip, as could be seen from the diagrams in the Paper, showed a numb of surfaces which did curve towards the top, but in general were all of a plane natur Towards the top of the slip near the curved portion, some of the surfaces pointed towar the toe of the wall, but nearer the wall no such surfaces had been found. Mr Palm thought that the very nature of borehole sampling made that rather difficult, and matter of chance. Taking a line from the base of the wall to the part where the slip su faces curved upwards showed that the angle of the slip was 35°, and in the analysis h thought that the worst failure plane had been at 35° to the horizontal. That was remarkable agreement, but it supported the contention that had been made in the pa that the C, ϕ effective stress analysis was much more likely to give the true position the failure plane.

The zonal nature of the slip failure, he thought, had been confirmed by re-examinatio of the undrained shear strengths. There was a suggestion in the Paper, based on th soil mechanics report, that the average strength of the blue clay clear of the slip zone wa less than that of the brown clay, which was somewhat surprising, and he did not belie that it was true. The trouble was that most of the samples in the blue clay had bee taken in the zone which had to be regarded as part of the failure zone, and therefor although they had not appeared to be softened on inspection, it seemed likely that the had suffered from softening in the course of time. No true comparison of unsoftene strengths was therefore possible.

He therefore submitted that the failure had, generally speaking, confirmed Coulomb assumption. The fact that the slip surfaces marked in the diagram were the only on that had been discovered really arose from the difficulty of discovering them in trench by spade work. The first had been discovered purely by chance, when a chunk of cla had slipped off along the slip surface, and of course from then onwards very caref spade work had been done to find further slip surfaces; there were probably many mo which had not been discovered.

He thought it had been shown that, although the Coulomb assumption about the single ane of a sliding surface was a reasonable one, the existence of several planes which did t lie in the same line would have a sobering effect on future investigations.

It also occurred to Mr Palmer just how unhelpful was the total stress $\phi = 0$ analysis of at type of failure. The Code of Practice suggested that one should estimate how much e clay softened in time, but the problem remained of how to make that estimation. it really was a question of an intelligent guess based on various failures which had en examined in the past. The average strength in the slip zone had been about 000 lb/sq. ft. It did not agree with the $\phi = 0$ analysis. He had been interested to hear r Cassel's remarks on the shear strength in the slip zone but, with the shear strength rying so greatly, and lacking a very large number of shear tests, it was difficult to agine how the actual true average softened shear strength would have been determined. he investigation had demonstrated how very difficult it was to determine the average ftened strength. Boreholes would have been even less helpful in that respect, because the difficulty of locating any slip surfaces at all, and any estimate made of the softened rength from boreholes would be even less accurate.

About 6 years previously Mr Palmer's firm had been engaged in the investigation of me slips in a railway cutting in the Midlands. The cutting was 50–90 ft deep in stiff ulder clay. No slip planes, or extensive or relevant softened zones had been found the site of those slips. A number of analyses had been done on the total stress basis $= 0$), and the section on the drawing board had resisted every attempt to make it il, showing stupendous factors of safety of the order of 3 and 4. He thought it was fair admit that they had been baffled. It could only be suggested at the time that the ip was associated with the layer of water-bearing silt and that, in order to examine rther the nature of the slip, it was essential that piezometers should be installed. The xbridge slip showed the necessity for installing piezometers as well as determining the ometrical proportions of the slip and the effective stress parameters. It seemed far ore important to find the position of the water-table than that of the slip surface. ith regard to the slips in the Midlands to which he had referred, he thought that if they ad known then what they knew now, the C, ϕ effective stress analysis might have been ore successful.

The investigation had disproved the belief held by many engineers that there was no ater-table in clay. Excavations could be made in London Clay without disclosing any ater; yet there was a water-table, as could be very easily demonstrated by means of ore-water-pressure points.

He had been interested in Mr Bartlett's remarks about the practical difficulties of pplying the C, ϕ analysis to slip problems because of the urgency of dealing with them. r Palmer did not entirely agree. For one thing, being wise after the event, the analysis ould be done very rapidly once the investigator knew what he was doing. Secondly, e thought it was fair to say that London Clay had a drained angle of shearing resistance about 20° and would not vary very much from that. The near future might bring ore knowledge of how to assess its effective cohesion in particular cases.

Mr D. J. Ayres (Senior Engineering Assistant, Soil Mechanics Laboratory, British ailways, Western Region) was interested in the Author's observation that, although a mple had been taken through the slip plane there had been no visual evidence of that lane on extraction and examination of the soil. He felt that that was not always true nd that a slip plane could often be located from borings. He referred to an investigation ade in 1952 upon the failure of a retaining wall in a cutting through the London Clay, a time before the effective stress analysis for clay had been published and before the kathene-tube method mentioned by Mr Bartlett had become available.

The site was a 50-ft-deep cutting carrying the London Midland Region track, and out the side of the cutting emerged the Western Region line from Marylebone, about 20 ft igher than the London Midland track, crossing by a bridge to pass into the cutting at e opposite side.

A buttress had been constructed to prevent further motion of a cracked wall retainin the clay of the Western Region cutting. Mr Ayres showed slides illustrating the com plexity of the site and the relative movements which had taken place, from which h inferred that there was no simple mechanism of failure upon which stability calculatio could be based. Borings had been put down behind and in front of both the Weste Region and London Midland Region walls. He had himself examined every augerf of clay, searching for any sign of a slip plane. None had been seen there or in th samples, which would accord with the findings mentioned in the Paper. He had, howeve noted a continuous thin lens of water-bearing silt several feet below the surface of the so behind the Western Region wall. A mass of soil moving on that original layer deposition towards the London Midland cutting, would by virtue of its trapezoidal sha exert a sideways thrust on the Western Region wall and account for the various movemen observed. Slip planes in cuttings in London Clay located by the alkathene-tube metho had been found to end as long horizontal planes. Did the Author think that the dip the bedding planes in laminated soils affected the position of the plane of failure?

Mr Ayres suggested that a fissure could be defined as a plane in a cohesive soil separatin two soil surfaces, upon which surfaces, when the soil was in a saturated condition the occurred a film of free water. Such a plane could be seen with a powerful hand lens an was most easily observed in stiff fissured clays.

Observation of the fissure structure of London Clay showed a common pattern wit depth. For example, from the natural ground surface to about 5 or 6 ft depth was multi-fissured material of orange, grey, and brown mottled clay with fissure plan about $\frac{1}{8}$ in. to $\frac{1}{4}$ in. across their surface. From 6 ft to about 15 ft, fissures of from $\frac{1}{4}$ i to 1 in. across their surface occurred, having a light blue surface which seemed to coinci with the depth of fine hair roots, the clay being a rich light brown. From 15 ft to 30 the blue in the fissures disappeared, after which the clay became a darker brown and th fissures increased to 3 in. across or more. Below that depth the clay became a dirt grey and consequently was referred to by everybody as "blue", whilst the fissures we curved planes 1 ft or more across. The colour change took place over millions of year so that the so-called blue clay occurring at a depth of 15 ft under the Thames alluvi gravel would indicate that it had been covered previously by 30 ft or more of cla overburden. That type of information might be useful in investigating those properti of soils which were related to the history of their formation.

Mr R. F. Bonny (Works Maintenance Assistant, British Railways, Eastern Regio presumed that Mr Cassel's comments on horizontal drainage for a cutting slope behind retaining wall referred to the slip which had started behind the wall at Wood Gree station on the Eastern Region in 1947. The initial remedial measures, which include sheet-piling at the toe and insertion of hanging counterforts, had failed to arrest wa movement, so two trial drainage wells had been sunk in the slope and connected weepers through the wall by horizontal boring.

TABLE 3

1954	Observation well No.									
	10		9		2		8		7	
	ft	in.	ft	in.	ft	in.	ft	in.	ft	in.
January	4	11	4	11	23	2	6	0	5	0
February	4	10	4	10	23	2	5	8	4	1
March	4	0	3	2	23	2	4	5	3	4
April	4	4	4	4	23	2	4	11	4	1
May	5	4	5	4	23	2	6	6	5	7
June	5	9	5	10	23	2	6	5	4	10
July	5	0	4	10	23	2	5	7	5	0

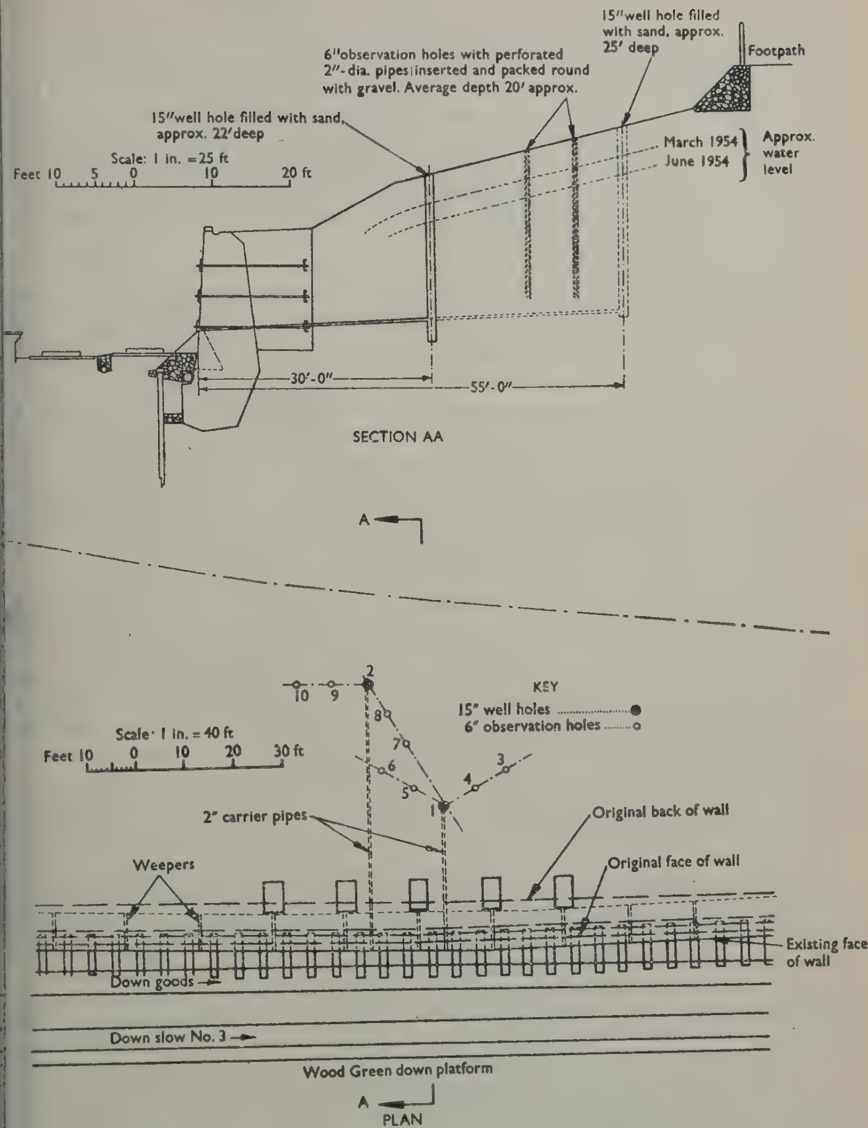


Fig. 25.—Wood Green wall. Experimental drainage wells

Fig. 25 showed the positions of those wells and the positions of observation wells spaced at 7½ and 15 ft from them. Table 3 listed the observations that had been made for one group of wells over a period of 6 months, the depths having been measured below ground level at the head of each well in the first week of each month.

It would be noticed that no significant reduction in the general water-table level had

occurred in any of the observation wells—even in those nearest to the drained well, in which the water levels indicated that it had been functioning at all times. A series of such drained wells had been considered but the proposal had been abandoned in the light of the above observations. The slope had recently been extensively grouted by the "Aerocem" process, the results of which were awaited with interest.

With regard to the mass-concrete struts at Uxbridge, Mr Bonny was rather surprised to note that the forward movement of the wall had been arrested so soon after their construction. It might be thought that a movement of 6 in/day would not have permitted the concrete to set properly and develop its full strength. Had a rapid-hardening cement been used or had the strut been stopped short of the wall foundation in order to allow it to harden off before the wall closed up to it?

The Author, in reply, thanked Mr Dunton for filling in the many gaps in the Paper. He also paid tribute to the Permanent Way staff of L.T.E. on whom had fallen the major responsibility for the work which had been done.

Dr Golder's questions were of outstanding interest to engineers. They had been partially answered by the other speakers, notably Mr Henkel and Mr Cassel. Mr Henkel connected a decreasing value of the cohesion intercept C with age (Fig. 23). It might be deduced from that figure that at 15 years after construction a retaining wall was entering a "dangerous age". Mr Cassel had suggested that had the presence of a high water-table been established that might have warned the engineers that a slip was likely or imminent. Combining those ideas, the measurement and plotting of the water-table and a stability calculation based on the effective stress method taken in hand say 10–15 years after construction, might be a valuable routine for maintenance engineers to adopt.

Mr Stripp had co-operated fully with L.T.E. and particularly so in finding accommodation for the occupants of the two houses which had been demolished. It was difficult to assess the relative value of the measures taken to stop the movement of the wall but an attempt to do that had been made in the Paper. No deterioration of concrete which could be attributed to gypsum had been noticed. Mr Stripp had asked to what extent the two buildings, 65 and 67 Montague Road, had contributed to the slip. The answer seemed to be not at all, because the tension cracks, at the top of the slip plane, had occurred between the buildings and the retaining wall. He agreed with Mr Stripp that railway and local authority engineers ought to co-operate to the fullest extent.

He considered that Mr Henkel had made a very valuable contribution to the discussion. For design purposes and for assessing the factor of safety of an existing wall the $\phi_d = 20°$, $C_d = 0$, effective stress analysis would give a safe result in the London Clay.

Mr Brown had made a unique contribution to the discussion as he had been an eye-witness of the 1938 slip. With regard to the design of future walls, it would appear that the effective stress method under $\phi_d = 20°$ and $C_d = 0$ and a low factor of safety, possibly 1·25, would give a safe and economic result. The Author agreed that a wall curved in plan was more resistant to tilting than a straight wall.

Mr Bartlett had described an interesting and practical method of locating an active slip plane by using polythene tubes and a plumbing mandrel. The Author thought that that method could be used to locate a slip plane quickly in the case of an active slip and the information which was obtained would be very valuable in designing remedial measures.

Mr Cassel thought it regrettable that it had not been possible to take the trial trench deeper. The difficulty had been that they could not get rid of the surface water encountered without heavy pumping—which had been considered inadvisable. Had it been proved that the slip had been circular and not wedge shaped, the Author doubted whether that would have affected the analysis to any great extent. Mr Palmer had dealt with the difficulty of obtaining a true average value of shear strength, but the adoption of the $\phi_d = 0$, $C_d = 0$ analysis had eliminated that difficulty and the time absorbed in making drained tri-axial compression tests had no longer been relevant. He found that no correction had been made for the thin rubber membranes used in the undrained tests. An appropriate correction was 0·2 lb. and that had been considered negligible. The crack in

he retaining wall at Uxbridge had been under observation since 1940, but unfortunately no one had connected it with a possible slip failure.

The Author had been particularly fortunate in having the benefit of Mr Palmer's help and advice in the preparation of his Paper and in the reply to the discussion.

Mr Ayres had asked whether the dip of the bedding planes in laminated soils affected the position of the plane of failure. The Author considered that at the Uxbridge site the slip plane was quite independent of the bedding planes of the clay.

Mr Bonny's observations at Wood Green had, no doubt, been disappointing. The Author wondered, however, if those interesting drainage measures would not, in the long run, reduce the level of the water-table.

Mr Bonny had referred to the struts. Rapid-hardening cement had been used and pads of Celotex inserted across the axis of the struts to cushion the force as the concrete set. Further, all the struts had not been cast at one time, so that the passive force had been able to build up gradually. The Author would not have been surprised if the struts had been shattered by the movement of the wall, but in fact there was no evidence of that.

The closing date for correspondence on this Paper has now passed. No contribution has been received.—SEC.

ROAD DIVISION MEETING

10 April, 1956

Mr Arthur Floyd, Member, Chairman of the Division, in the Chair

The following Paper was presented for discussion and, on the motion of the Chairman, the thanks of the Division were accorded to the Author.

Road Paper No. 51

DESIGN OF ROAD INTERSECTIONS

by

* **Kenneth Summerfield, M.Sc., A.M.I.C.E.**

SYNOPSIS

In relation to other causes of road accidents, road intersections represent the greatest single hazard. Any programme of improvement would be most profitably concentrated on main-road intersections where accident frequencies are overwhelmingly greater than on minor roads. An analysis of the accidents which occur shows the relative dangers of the various movements of vehicles at an intersection, and suggests why accidents happen. The Paper attempts to analyse the requirements of each movement associated with a three-way intersection of two-lane carriageways on a single level, to give a maximum degree of safety with a minimum interruption to traffic flow, and makes recommendations with regard to layout, carriageway marking, signing, and visibility to meet the needs of each manœuvre. The solution achieved is applied to three-way intersections on three- and four-lane carriageways. The Author urges boldly planned full-scale experiments.

Introduction

In Oxfordshire, a county with 1,620 miles of publicly repairable roads, there are about 2,200 intersections. They occur at the rate of one every 750 yd on trunk roads, one every 800 yd on class 1 roads, one every 950 yd on class 2 roads, one every 1,300 yd on class 3 roads, and one every 1,500 yd on unclassified roads. These junctions are the scene each year of about 350 accidents, or 18% of the total number in the county, involving, on the average, 6 deaths, 60 serious injuries, 140 slight injuries, and 250 collisions in which no bodily injury is caused. In relation to other causes of accidents, intersections represent the greatest single hazard. Their comparative position is illustrated in Table 1.

The average annual occurrence of accidents at intersections on the different classes of road is shown in Table 2, which indicates that accident frequencies are overwhelmingly greater on major than on minor roads, and that it is upon the former that any programme of improvement would most profitably be concentrated. It is therefore proposed to consider primarily intersections on major roads in rural areas, at which, by virtue of traffic volume and accident frequency, the expenditure involved in any improvement would be most readily justified. On roads carrying a

* The Author is Deputy County Surveyor, Oxfordshire.

heavy volume of traffic, for example in many built-up areas, intersections are, in addition, the main cause of delay and congestion, and their need for improvement is likely to be established primarily on these grounds.

Unless some dramatic and unexpected change occurs in the basic pattern of transport in Great Britain a large-scale programme of road works cannot be long delayed, and indeed the beginnings of such a programme have already been announced. It is therefore opportune to re-examine the principles of design upon which such a programme should be founded; and here engineers in Great Britain are in a sense fortunate, because although the ruling designs of the Ministry of Transport have, through lack of funds, been but little tried, there are available the fruits of research at home and the practical experience of many countries abroad.

TABLE 1.—ANALYSIS OF VEHICLE MOVEMENTS INVOLVED IN ACCIDENTS, OXFORDSHIRE 1952

Accident movements	Number of accidents	Percentage of all accidents
Intersection	353	18·4
Head-on	296	15·5
Overtaking	285	14·9
Stationary vehicle	207	10·4
Halting or slowing-down	133	6·9
Total classified	1,274	66·1
Total not classified	653	33·9
Total, all accidents	1,927	100·0

TABLE 2.—AVERAGE ACCIDENT FREQUENCY PER INTERSECTION ON DIFFERENT CLASSES OF ROAD

Class of road	Average number of accidents per intersection per annum	
Trunk	0·70	0·50 main roads
Class 1	0·30	
Class 2	0·14	0·09 minor roads
Class 3	0·09	
Unclassified	0·05	

This Paper is therefore presented as a contribution to the study of intersection design, so that the eventual road system, whether based on an improvement of existing roads or upon new roads, should contain junctions which afford to all users a maximum degree of safety with minimum interruption to traffic flow.

BASIS OF DESIGN

Unlike other forms of engineering design which involve an appreciation and application of the laws of inanimate nature, highway design involves the element of human behaviour, and is therefore not entirely susceptible to precise forms of design based

on an observance of the natural law. Any conclusions drawn from human behaviour can only approximate to the truth, and the designer must have as much regard to the abnormal as to the normal. Accidents occur primarily as a result of a lack of timely appreciation of a situation, and it is therefore of the essence of good design that it reduces the number of occasions on which unexpected or complex situations arise, and that it points the way to a natural and simple course of action when they do. Design thus becomes a blend of applied scientific principles and an analysis of human behaviour based on observation and accident investigation, and the geometric design of road intersections based on the mechanical characteristics of vehicles is not likely to prove successful unless it also takes into account the human reaction to it.

For this reason the merit of any proposals can in the last resort be judged only by full-scale experiment, and it is to be hoped that trials on a much bolder scale than have hitherto proved possible may be permitted. Whilst there may be a natural reluctance to embark upon any such trials of a layout embodying hitherto untried features of design, it has to be borne in mind that more than 50,000 accidents occur annually at intersections in Great Britain, at the majority of which sites little or nothing is at present being done to improve the accident rate, and, in the Author's view, an element of risk would be amply justified in view of the subsequent great saving in life and limb.

Rural three-way intersections on two-lane roads

In order to simplify the approach to the basic problems of intersection design, it is proposed to consider the elements which should compose the layout of a simple three-way junction of two-lane carriageways on a single level, giving the maximum degree of safety with the minimum interruption of traffic flow. Having arrived at a solution it is then proposed to apply it to other types of junction, and to make a comparison with the cost of currently accepted layouts.

Table 3.—Frequencies of different types of accidents at three-way intersections and percentages of accidents involving two vehicles (one turning)

Oxfordshire—Accident analysis 24—Rural sites 1946–1954 (318 accidents).
Bennett—Road Junctions—Suggestions for improved designs 1947.
Road Research Laboratory—(J. C. Tanner) Analysis of accidents at (232) rural three-way junctions (390 accidents).

	Oxon %	Bennett %	R.R.L. %
LEFT IN - ONCOMING	0	0	1·0
LEFT IN - FOLLOWING	1·5	0	2·3
RIGHT OUT - FOLLOWING	9·4	16·0	11·0
RIGHT OUT - ONCOMING	14·3	24·0	22·6
LEFT OUT - ONCOMING	3·1	4·0	5·5
LEFT OUT - FOLLOWING	8·5	6·0	8·0
RIGHT IN - FOLLOWING	52·5	43·0	34·0
RIGHT IN - ONCOMING	17·6	7·0	15·6

Vehicular accidents at three-way intersections

Investigation shows that the degrees of hazard involved in the various vehicular manœuvres at three-way junctions vary considerably, as might be expected, from site to site according to topography and the volume and direction of traffic flow, but that the average of a number of sites taken either in different parts of Great Britain, or at different times, presents a marked consistency. It is thus possible to generalize and compare the relative dangers of the various movements.

Tables 3 and 4 show the number of accidents in the past 9 years attributable to the various movements at twenty-four simple three-way junctions in Oxfordshire, and gives for comparison the results of an investigation conducted in 1947 by the late

Table 4.—Frequencies of different types of accidents at three-way intersections and percentages of all accidents involving turning vehicles

Oxfordshire—Accident analysis 24—Rural sites 1946–1954 (368 accidents).
Road Research Laboratory—(J. C. Tanner) Analysis of accidents at (232) rural three-way junctions (523 accidents).

	Oxon %	R.R.L. %
LEFT IN - ONCOMING	0	0·8
LEFT IN - FOLLOWING	1·4	1·7
RIGHT OUT - FOLLOWING	8·2	8·2
RIGHT OUT - ONCOMING	12·2	16·8
LEFT OUT - ONCOMING	2·7	4·2
LEFT OUT - FOLLOWING	7·4	5·9
RIGHT IN - FOLLOWING	45·3	25·2
RIGHT IN - ONCOMING	15·2	11·7
RIGHT IN - LEFT OUT LEFT IN - RIGHT OUT	4·1	12·6
LEFT IN	0·3	2·5
LEFT OUT	1·6	4·0
RIGHT OUT	0	2·9
RIGHT IN	1·6	3·4

Left-in	denotes	movement of a vehicle turning left from the major road into the minor road (Movement 3).
Left-out	,,	movement of a vehicle turning left out from the minor road into the major road (Movement 5).
Right-in	,,	movement of a vehicle turning right from the major road into the minor road (Movement 6).
Right-out	,,	movement of a vehicle turning right out from the minor road into the major road (Movement 4).
Following vehicle	,,	vehicle travelling along the major road in the same direction as the turning vehicle and behind it (Movement 1 or 2).
On-coming vehicle	,,	vehicle travelling along the major road in the opposite direction to the turning vehicle and in front of it (Movement 1 or 2).

Col. G. T. Bennett[1] from junctions in the county (some of which were included in the later survey) together with the results of an investigation undertaken by the Road Research Laboratory[2] in 1952 on 232 rural three-way junctions spread over eight counties in England and Wales over a period of 4 or 5 years.

It will be noted from the figures that the various movements are for convenience briefly described in the following terms. For comparison, the reference number of the movement adopted by the Road Research Laboratory is also given.

To avoid confusion, all references to practice and experience in countries where the right-hand rule of the road applies have in this Paper been reversed, "left" and "right" being interchanged to conform to British practice.

It is proposed to consider each movement separately and to deduce what features should be incorporated in the design of an intersection to meet its requirements.

Left-in movement

Requirements

This movement is the least productive of accidents in all the manœuvres associated with a three-way junction. Accidents from this source are the result of collisions with the on-coming or following vehicles, or of failure to negotiate the turn.

A study of the details of those accidents which occur suggests that the following basic features should be incorporated in any design:—

(1) The provision of facilities and encouragement to turning traffic to dissociate itself from the main stream before decelerating.
(2) Positive and advance guidance as to the route to be adopted by turning traffic.
(3) Clear indication to other traffic of the turning driver's intentions.
(4) Sufficient vision along the route to be followed by turning traffic for drivers to assess the speed at which the turn can be negotiated.
(5) Definition of throughway for main road traffic.
(6) Removal of any point of hazard from any other such point at the intersection.

Provisions

(1) *Layout*

Although collisions between a left-turning vehicle and the following vehicle are comparatively rare, an accident of this nature can be avoided entirely if adequate deceleration bays are provided, and drivers use them.

The dimensions of the current standard (Ministry of Transport and Civil Aviation) deceleration bay are shown in Fig. 1. Observation of the speeds and path of vehicles turning left-in at intersections laid out to these standards, however, shows that deceleration takes place almost entirely in the path of through traffic on the main road, as illustrated in Fig. 2,[3] from which it will be seen that only 14% of the turning traffic had completely entered the deceleration lane at the tangent point; and in Fig. 3, which shows that at this point the average speed of vehicles is about 17 m.p.h. It is clear that a more generous provision in respect of both the dimensions of the deceleration lane and the minimum radius are desirable if collisions involving the following vehicle are to be avoided. The questions at issue are : how much provision should be made for deceleration ; and how are vehicles to be encouraged to enter the deceleration lane before slowing down?

Clearly, the provision of a deceleration lane of sufficient length to allow vehicles to enter it at the full speed value of the road and allow them a sufficient distance in

[1] The references are given on p. 360.

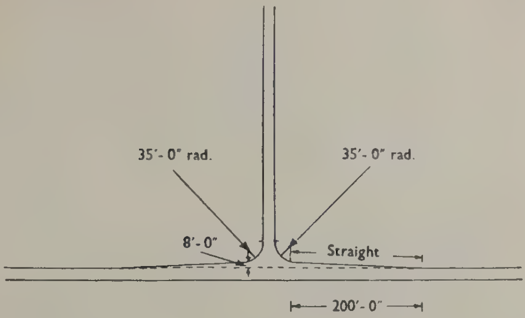


FIG. 1.—DIMENSIONS OF CURRENT STANDARD DECELERATION BAY

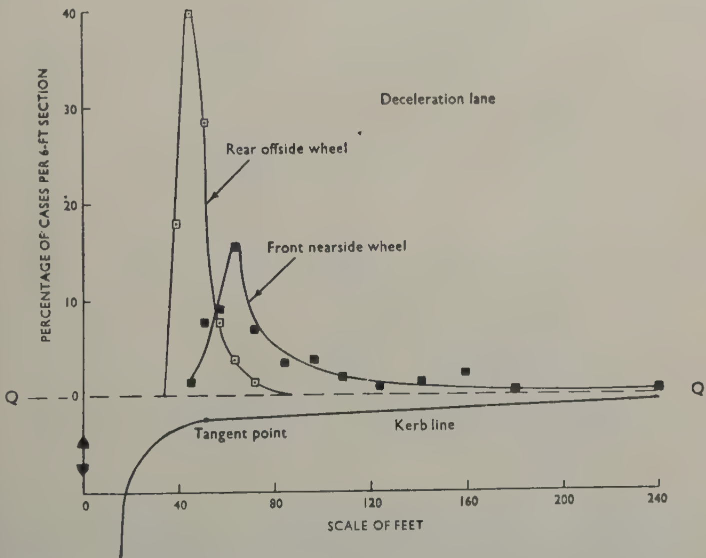
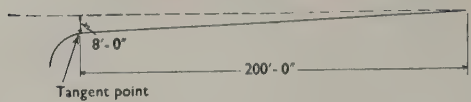


FIG. 2.—DISTRIBUTION OF LEADING- AND TRAILING-WHEEL POSITIONS ON LINE QQ, SHOWING USE OF DECELERATION LANE

hich to slow down and make the turn, offers the ideal solution in that no interrup-on to traffic flow or danger of collision with the following vehicle should result. But so generous a provision necessary? American practice is that a vehicle speed of 0% of the speed value of the road should be assumed for this purpose, and this gure is used in expressway design where uniformly higher speeds may be expected han on an all-purpose road. Although the speeds of vehicles do not appear to be erceptibly affected by the presence of intersections unless obstructed by a turning ehicle, it seems reasonable to suppose that a driver about to make a turn will pproach the intersection at something less than maximum speed. At this stage he ill initiate a dangerous situation only if the difference between his own speed and



DIAGRAMMATIC PLAN OF SITE

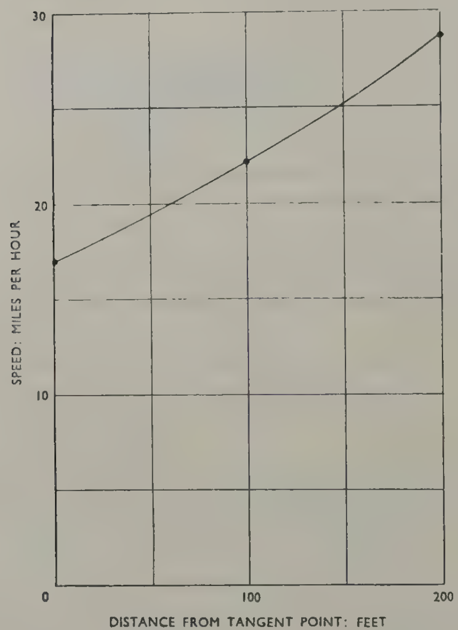


FIG. 3.—OBSERVED SPEED OF VEHICLES ON A DECELERATION LANE

that of the following vehicle is sufficient for the driver of the latter to be forced to brake hard, or to be tempted to overtake. Now if the turning driver is travelling at a uniform "normal" speed when approaching the junction, the hazard he presents is no different from that which he presents at any point on the road; it is only when he brakes to make the turn without a perceived warning that this occurs. Therefore it may be argued that provided a turning driver is able to leave the main stream at a near "normal" speed he should present no serious hazard, whether he gives any positive sign of his intention or not.

In determining what may be regarded as the "normal" speed of traffic on a particular road, it is of interest to note the distribution of vehicular speeds of through traffic at an intersection. Fig. 4 shows the actual recorded speeds at one such site and Fig. 5 shows the results plotted to show the cumulative frequency distribution of vehicle speeds. Although the highest speed recorded at this point was 76 m.p.h. 89% of the traffic travelled at less than 70% of the speed value of the road (based on Ministry of Transport standards as shown in Table 5), and 66% at less than 60% of the speed value. As seen in Fig. 6, speeds recorded at other sites show similar results.

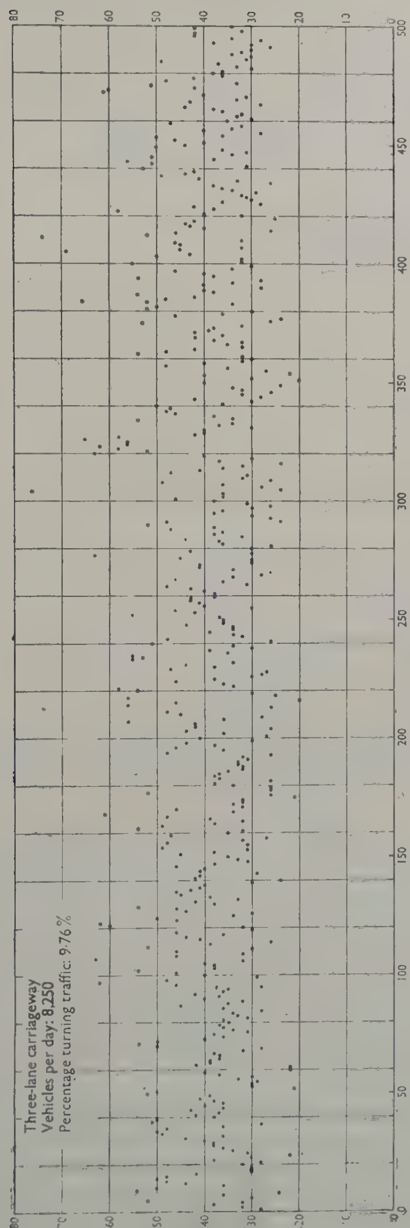


FIG. 4.—RECORDED SPEEDS OF THROUGH VEHICLES AT A THREE-WAY INTERSECTION ON A TRUNK ROAD

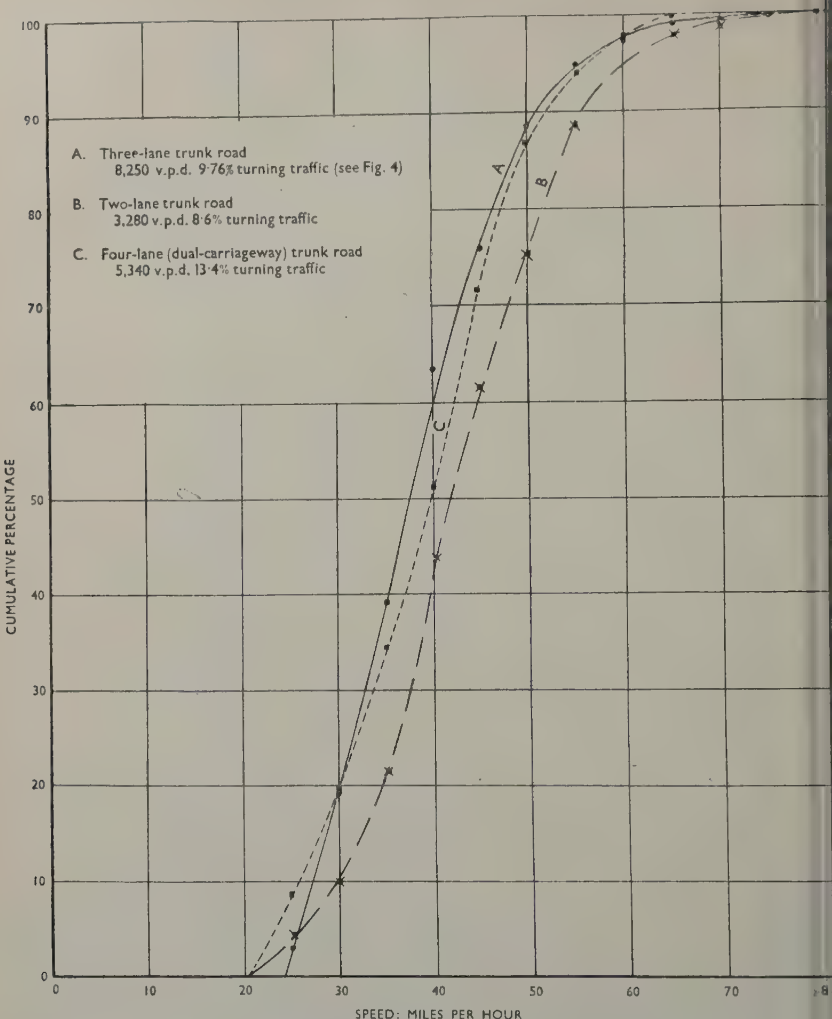


FIG. 5.—CUMULATIVE FREQUENCY DISTRIBUTION OF VEHICLE SPEEDS ON TWO-, THREE-, AND FOUR-LANE ROADS

from which it would appear that a figure of 70% of the speed value of the road wou embrace all but a small proportion of the traffic using it, and such speeds could b regarded as "normal" for the road. It would therefore seem reasonable to mak sufficient deceleration provision for drivers to enter the deceleration lane at 70% of the speed value of the road.

It is perhaps relevant to mention that on American expressways with very hig speed values (based on standards of visibility) it is becoming the practice to impo speed restrictions of 60 m.p.h.; and on heavily trafficked roads there is much to

TABLE 5.—MINISTRY OF TRANSPORT VISIBILITY STANDARD
(based on Memorandum No. 653)

Speed value of road: m.p.h.	Visibility distances: feet	
	Dual carriageway	Single carriageway
20	100	150
30	150	250
40	250	450
50	350	650
60	500	900
70	650	1,200

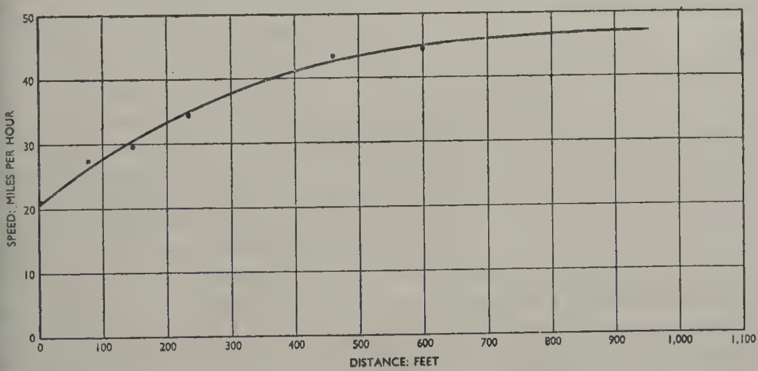


FIG. 6.—OBSERVED SPEED AND DECELERATION OF VEHICLES APPROACHING A ROUNDABOUT IN OXFORDSHIRE

aid in favour of imposing an upper limit to speeds, even if higher speeds are theoretically safe, because there is no doubt that as speeds advance, exceptional handling skill and alertness is required of drivers, to a higher degree than can reasonably be expected from those not possessing the necessary aptitude and training. If such an upper limit was to be imposed in Great Britain it is, however, unlikely that it would materially affect the general pattern of speed distribution below the maximum, and a "normal" figure of about 50 m.p.h. would probably remain an appropriate basis for intersection design.

In deciding the length of deceleration lanes necessary for various speeds of entry, the minimum radius of the exit must first be determined, as this figure governs the safe speed of exit. Clearly the minimum radius and length of deceleration lane are directly related, as the higher the turning speed, the shorter is the length of deceleration lane required, and it is therefore necessary to arrive at a balance between these two factors. In determining where this should be it must be borne in mind that whilst vehicles should be encouraged to leave the main carriageway at as high a speed as possible in order to reduce the risk of collision and interruption of traffic flow, it is at the same time desirable that they should make the turning movement at a more controlled speed, because they are usually entering a minor road of lower speed value, and, moreover, other vehicles perhaps making other movements at the

junction simultaneously present an additional hazard if speeds are too high. further point to be considered is that large turning radii involve a wide expanse o paved area unless additional islands are provided, and the latter are to be avoide as far as possible because they inevitably add to the complexity of the junction, an for this reason create an additional risk.

With these considerations in mind it is suggested that a minimum radius of 50 f should be adopted, giving a safe turning speed of 20 m.p.h. This figure is based o the theoretical minimum safe radii for various turning-speeds, adopted by th American Association of State Highway Officials,[4] as set out in Table 6, and is con firmed by experiment. Whatever minimum radius may be adopted, it is importan that adequate transition should be provided, or drivers will make their own transi tions and fail to follow the kerb line. If this occurs the deceleration lane is to som extent wasted, and the movement becomes dangerous when the vehicle emergin from the curve swings on to its offside in the face of on-coming traffic. On what ma be the ideal curve for this purpose there will undoubtedly be strongly held an divergent opinions, but this is pre-eminently a matter for full-scale investigatio because driver behaviour is an important factor to be considered. It has, howeve to be borne in mind when selecting a suitable curve that the requirements differ fro those which apply to the design of transition curves on a through carriageway in s far that the majority of vehicles travelling along the transition will undoubtedly d so during a period of marked speed change. Observations on the speed of vehicle approaching a roundabout on a road in Oxfordshire having a high speed value wher it was necessary to reduce speed to 15–20 m.p.h. suggest that in these circumstance the majority of drivers travelling at higher speeds decelerate in gear to a speed o 30–35 m.p.h. at a distance of about 150 ft from the point of entry before braking as illustrated in Fig. 6. If driver behaviour were similar on a deceleration lan there would seem to be much to recommend a curve which would create a unifor centrifugal force throughout its length on a vehicle reducing speed at a uniform rat from 35 m.p.h. at the beginning of the curve to 20 m.p.h. at the point of minimum radius; and it would be of interest to study driver behaviour on such a curve.

TABLE 6.—MINIMUM SAFE RADII FOR VARIOUS TURNING-SPEEDS

Turning-speed, V: m.p.h.	20	30	40	50
Coefficient of friction at impending skid	0·7	0·6	0·5	0·4
Safety factor used	1·3	1·4	1·5	1·6
Design coefficient of friction, f	0·54	0·43	0·33	0·25
Assumed super-elevation, e	—	0·05	0·10	0·10
Total: $e + f$	0·54	0·48	0·43	0·35
Calculated minimum safe radius: ft $R = \dfrac{0{\cdot}067 V^2}{e+f}$	50	126	246	476
Suggested minimum safe radius: ft	50	130	250	500
Suggested curve of even degrees	—	45	23	11

The length of the deceleration lane should be sufficient to allow for a natural an comfortable reduction in speed from 70% of the speed value of the main road t 20 m.p.h. at the point of minimum radius. A study of the behaviour of vehicles i America,[5] and recorded in Fig. 7, Plate 1, suggests a length of 300 ft on a roa having a speed value of 60 m.p.h. It will, however, be necessary to make som

addition to the minimum figure to allow for the fact that drivers usually travel with their nearside at least 3 ft from the kerb line, nor in American experience do they usually enter a deceleration lane precisely at its starting point. Fig. 8, Plate 1, shows the results of observations[6] on driver behaviour on a deceleration lane from which it would appear that the usual practice of drivers is to enter the lane at a point about one-third along its length, which is confirmed by observations[7] on the Pennsylvania Turnpike, where deceleration lanes 1,200 ft in length are provided.

The shape of the entry to the deceleration lane may take one of the forms illustrated diagrammatically in Fig. 9, Plate 1.

The form shown in Fig. 9a has advantages in that it follows the route to be adopted by traffic using the lane, and it provides a continuous kerb line in adverse weather conditions. Its disadvantages, in American experience, are that through traffic may enter a lane of this shape inadvertently and that vehicles are less tempted to enter a tapering lane than one of full width.[7] The layout shown in Fig. 9a would seem to be preferable on balance, but the relative merits of the two designs can be assessed thoroughly only by experiment.

(2) *Carriageway marking*

It is essential in any road layout that the route to be followed by all vehicles should be apparent by day and night under all weather conditions. At an intersection, this principle implies that the routes to be followed by both through and turning traffic should be clearly defined, and for this purpose carriageway marking is indispensable.

Although there are adherents to the belief that the nearside marking of traffic lanes is more suitable and convenient than offside marking, no satisfactory method of achieving this system has yet been reached, and offside marking, particularly with the aid of reflecting road-studs, is generally acceptable, having regard to the practical difficulties involved in any alternative; moreover, its use in Great Britain is now so widespread that any fundamental variation would be fraught with grave transitional difficulties. It is, therefore, considered that the marking of the through route at an intersection should follow current practice by providing a continuous white line with road-studs at close spacings on the offside of the through lane. It is, however, doubtful whether the authorized arrangement comprising a 100-ft length of continuous line 4 in. wide on each approach to an intersection is adequate, either in respect of the length or width of the line, particularly in that part of its purpose which should be to contain traffic in its appropriate lane and discourage overtaking. Distances consumed in an overtaking operation depend upon the absolute and relative speeds of the two vehicles concerned, and vary from a length of 600 ft for a vehicle travelling at 30 m.p.h. overtaking one travelling at 20 m.p.h., to 3,200 ft when the vehicle speeds are 70 m.p.h. and 60 m.p.h.[8] Even having regard to the restraint on the free movement of vehicles which greater lengths of continuous line would impose on a road with frequent junctions, it is imperative that vehicles are contained within their correct lane at an intersection if accidents are to be avoided. For this reason it is considered that the central continuous white line on a two-way road at the approach to an intersection should commence at the beginning of the deceleration lane, and that the width of line should be increased from 4 in. to at least 6 in.

The marking of the nearside of the lane presents some difficulty on account of the conflicting needs for direction of the through and the turning traffic. An intermittent line on the nearside across an opening is of great assistance to through traffic, particularly in time of fog, but it is suggested that the present scale of the line, namely

3-ft lengths at 3-ft intervals, is inappropriate having regard to the foreshortening effect and the high normal speeds of traffic on main roads today, and it is recommended that 6-ft lengths of line at 12-ft intervals and 6 in. wide would be more effective. However, widespread trials of possible alternatives are desirable.

It is important that some indication should be given to turning traffic of the path to be followed, and this can be achieved by appropriate signing as discussed in the following section, supplemented by arrows painted on the carriageway to assist drivers, particularly in time of fog. Once the turning traffic has cleared the through lane, it can be provided with a continuous line with closely spaced studs.

Contrasting surface treatment of the through carriageway and the turning lane has much to recommend it, and can be achieved by constructing the deceleration lane in a different material from that used in the through carriageway.

(3) *Signing*

It is proposed here to confine comment primarily to aspects of signing which directly affect intersections, although it is inevitable that general principles should also become involved.

The advance direction signing of important intersections is essential both for the guidance of drivers in sufficient time for appropriate action, and as a warning of the impending hazard. As a guide, the sign should indicate clearly the choice before the driver and the course of action he should take.

In the first place, at most T-junctions on a main road it is rarely necessary to provide more for the through traffic than confirmation of the main route, and to confine details to the places served by the branch road. As the importance of main roads becomes emphasized by improvement, and their character stands in greater contrast to that of the minor roads joining them, this principle will apply with greater force. For example, on a trunk road provided with dual carriageways throughout it hardly seems necessary to re-establish the destinations of the main road at each minor road junction, every half-mile, and it is very unlikely that the absence of this information would create a doubt in the mind of the through driver.

The suggested advance signing of the left-in movement is illustrated in Fig. 11, Plate 1. It will be noted that compared with the present authorized sign illustrated in Fig. 12, Plate 1, the proposed sign accentuates the importance of the main road; indicates the path to be followed by the turning vehicle; provides a sign which, although of larger size, is less of an obstruction to vision, and offers clearer indication of the destination by casting the names in larger letters and freeing them from the box into which current practice confines them. It will be noted that route numbers have been omitted entirely from the suggested sign, and this will undoubtedly be regarded by many as a retrograde step; but the Author is not convinced that the complex road system in Great Britain lends itself to a simple system of route designations, or that the importance attached to route numbers in relation to the destination of a road by highway authorities is shared by the travelling public. It would be of great interest if the motoring organizations were able to provide information on this point. It is, however, suggested that periodic confirmatory signs of the type illustrated in Fig. 13, Plate 1, might be usefully employed on main roads, but it is not envisaged that such signs should be erected more frequently than at intervals of about 5 miles or following a major intersection.

It is very desirable that at important intersections advance direction signs should be indirectly illuminated, if a source of electricity is available, because on a busy road drivers frequently approach an intersection with dipped headlights, and may

e to some extent blinded by the headlights of on-coming vehicles. If electricity is ot available, diagrams and letters can be provided with lenses for night definition, ut if this is contemplated there is much to recommend the use of white letters gainst a dark ground rather than the reverse, because the insertion of lenses ito black lettering severely detracts from the daytime clarity of the signs, whilst at ight the lenses stand out more conspicuously against a dark ground than a white ne. The use of an overall beaded background, which is another alternative, has the isadvantage of tending to a slight dazzle which obscures the letters, and in Great Britain the beads themselves collect dirt readily and lose their effectiveness during he winter months, particularly on low signs where they are often splashed by passing ehicles.

The layout of the sign can also guide the driver to approach the turning by way of deceleration lane, and not by making a simple right-angled turn as suggested by he current authorized sign.

Investigation of the time taken to read three place-names comfortably shows that nder ideal conditions a minimum period of about 2 sec is required. Making allowance or the fact that drivers are unable to concentrate their attention on a sign for a ontinuous period of this length, it is suggested that the minimum period required hould be assumed to be 3 sec. Fig. 14, Plate 1, shows the maximum sight distances t which persons of normal vision under average daylight conditions can read letters f various sizes. Allowing a minimum "exposure" of 3 sec, it would appear that n advance direction sign containing three place-names in 2-in. letters cannot be ead by a driver travelling at more than about 35 m.p.h., and that the minimum ize of letters required if drivers are to be able to read them at 60 m.p.h. is 4 in. It is uggested that this size should be regarded as the minimum for all advance direction igns on the approaches to intersections.

It will be noted that the place-names of villages on the route to which it is desired o give direction are mounted in lower-case letters. This method has the advantages of providing a contrast and of allowing a wider spacing between letters without a corresponding increase in the overall size of the sign, both of which make the sign more legible. The whole question of the legibility of signs is, however, a matter for expert investigation, and there is in this subject a wide scope for research and full-scale experiment.

The mounting height and set-back of advance direction signs is of some importance. By providing larger lettering and indirect lighting or lenses, it is possible to erect signs in rural areas in a higher position and farther back from the edge of the carriageway than is at present normal practice, and this alteration is advantageous in that the signs are then less of an obstruction to vision, are themselves less likely to be obstructed by other vehicles, and are less liable to be splashed by passing vehicles. The dimensions suggested are a mounting height of 7 ft to the underside of the sign, and a forward edge 6 ft from the carriageway. The signs should be set obliquely to the line of road, the exact angle for maximum effect being dependent upon the carriageway alignment.

The sign should be placed at a sufficient distance in advance of the beginning of the deceleration lane to enable a driver travelling at more than 45 m.p.h. to reduce speed in gear after reading the sign so that he can enter the lane at that speed, and assuming an initial speed of 60 m.p.h., this distance becomes about 600 ft.[9]

At the junction itself no provision is made for confirmatory flag-type signs or for a signpost. The fundamental assumption upon which the signing of intersections is based is that no driver arrives at the junction in any doubt as to the route he wishes

to follow. An attempt has been made to provide advance direction signs of the utmost clarity, followed by a road layout and carriageway marking which guide the driver to his proper course, and it is of the essence of the design that no further guidance should be necessary; and if it is necessary, the design has failed in its purpose. By freeing the immediate surroundings of the junction itself of all obstructions to vision and distractions to the driver, a marked step towards road safety can be achieved in that the driver is given the opportunity to concentrate on the movements of any other vehicles in the vicinity.

(4) *Visibility*

A driver leaving the main road, and turning left into a minor road, does not require so extensive a range of vision as does an emerging driver, and the line of the highway boundary is therefore governed by the latter's requirements, which are discussed later. Nevertheless, the driver leaving the main road should at all times have sufficient forward vision to enable him to apprehend the route he has to follow within the compass of his comfortable stopping distance, plus a margin to give him a confidence that he will not suddenly be confronted by an unforeseen hazard, and for this purpose a minimum addition of half to his stopping distance would seem to be sufficient. The highway boundary line shown in Fig. 17, Plate 1, has therefore been checked to ensure that it fulfils this requirement.

Left-out movement

Requirements

This movement ranks next after the left-in movement in productiveness of accidents at three-way junctions, and is, in general terms, about eight times as dangerous as that movement. Accidents from this source are predominantly the result of collision with the following vehicle, although a number of collisions with the on-coming vehicle and single-vehicle accidents also occur. A study of the circumstances in which these accidents have occurred suggests that the prime cause is the emergence of the vehicle from the minor road in too wide an arc at a time when the following or on-coming vehicle, by reason of proximity or lack of manœuvring space, cannot slow down or take avoiding action. The accidents suggest that the driver of the vehicle emerging from the minor road either fails to appreciate that he is entering a major road, or misinterprets the speed of oncoming traffic. Clearly, a vehicle entering a main road can do so with perfect safety so long as that road is free from traffic. It can equally well do so without either endangering or inconveniencing the main road traffic, if the motorist correctly judges the time required to enter the main road and accelerates to the speed of the main road stream. If he is required to enter that stream from a stationary position at right angles to the main road traffic, he offers the maximum obstruction when he emerges and occupies the through lane for a long period while accelerating. Moreover, in a stationary position at the edge of the main road carriageway, he is placed where he is least able to judge the speed of approaching traffic, because on a straight and level road he is presented with a frontal silhouette of the approaching vehicle. Clearly, the greater his lateral displacement, the better he is able to judge that speed; and furthermore, the less likelihood there is of vehicles in line on the main road masking one another. Similarly, a driver travelling along the main road, and faced with a stationary vehicle on his near side waiting to emerge, is in a dilemma. He cannot be sure that it will not enter his path at low speed, although he may assume that it will not do so, and the fact that collisions frequently occur in these circumstances shows how real the dilemma is.

The basic requirements for the left-out movement at a three-way junction thus become:—

(1) The point of minimum velocity of an emerging vehicle to be sufficiently remote from the main road carriageway for the driver to be able to assess the speed of on-coming traffic and for the main road driver to assess the other driver's intentions.

(2) Adequate vision for each driver to have the other in view during the whole of the movement.

(3) A sufficient acceleration lane for the minor-road vehicle to enter the main stream at the speed of that stream.

(4) Clear guidance to the driver of the emerging vehicle of the route he has to follow.

(5) Definition of the through lane.

(6) Removal of the point of hazard from the other points of hazard at the intersection.

Of these requirements the most contentious is the third, because it raises the question of priorities between through traffic and emerging traffic. The fundamental precept governing driver behaviour in Great Britain at present is that the minor-road vehicle should in every case give precedence to the one on the main road, and this is emphasized by the provision of Halt and Slow Major Road Ahead signs. For this reason there are no comparative accident statistics on which to assess the relative safety of the two opposing principles, nor are there figures available from experience abroad, because for the most part intersections designed on the principle of high speed of entry are confined to motorways and expressways where the general standards of design are uniformly higher than on other classes of road. Nevertheless, it may be relevant to quote the experience in the State of New Jersey, where in 1954 the ratio of intersection accidents to all accidents on expressways was 15·4% compared with a ratio of 41·3% on all other roads in the State.[10] These figures must, however, be treated with reserve, because on expressways, accidents at intersections can only result from the left-out and left-in movements and cannot involve the on-coming vehicle, and accidents between intersections cannot include head-on collisions. Investigation by the Road Research Laboratory[11] suggests that at uncontrolled intersections the accident rate at oblique right-hand splays is 32% of the corresponding rate at square junctions, and lends support to the belief that the more nearly vehicles executing the left-out and right-in manœuvre enter and leave the main stream parallel to the direction of that stream, the less likelihood there is of an accident occurring.

The fundamental concept upon which high entry speed is to be preferred to low entry speed is that in the former the entering vehicle forms less of an obstruction, and collisions are therefore less probable, and when they do occur, less severe. On any road with vehicles travelling at different speeds, front to rear collisions may occur, but when they do, there is a *prima facie* case against the following driver. When a vehicle enters the main stream at speed the following driver can overtake or fall behind. Theoretically, if the entering driver gives way at a right-angled junction this situation should not arise; but accident statistics show that in practice it does. As the volume of traffic on all roads increases, the occasions when a vehicle can enter the main stream without causing danger or inconvenience are reduced, until at a busy junction it becomes almost impossible to do so, and the right-angled design fails to function. In these circumstances vehicles build up on the minor road, and the risks increase because the second and third vehicles tend to follow the

leader into a decreasing gap. By providing an acceleration lane, the following vehicle on the main road has greater opportunity for timely appropriate action, and, if the lane is of sufficient length, has ample time to decide whether to overtake the emerging vehicle or whether to fall behind it. It will thus be seen that if a driver emerges heedlessly, the driver of the following vehicle on the main road can take the necessary action with much greater ease and certainty of success than is possible in these circumstances in the orthodox layout.

Provision

(1) *Layout*

The current authorized layout provides a 35-ft radius and a short acceleration bay as shown in Fig. 2. Thus at the point of minimum speed of the emerging vehicle it is less than 15 ft from the edge of the main carriageway. Whilst it is desirable that the speed of the emerging vehicle is checked, so that the driver has his vehicle well under control while deciding on his course of action, it is important, for the reasons given in the preceding paragraph, that the point of minimum speed should be considerably more than 15 ft from the edge of the main carriageway. The actual velocity to which it is desirable that speed should be reduced at this point cannot be precisely defined but clearly the lower the minimum speed, the longer the acceleration lane needs to be if vehicles are to enter the main stream at normal speeds. On the other hand large radii tend to lead to wide areas of carriageway which are not desirable unless required for manœuvring. There are in fact three factors which are all interrelated and it is necessary to strike a balance between them. They are (1) the desirable minimum radius, (2) the length of acceleration lane, and (3) the distance from the point of minimum radius to the nearest point on the main carriageway.

Fig. 10, Plate 1, shows the aspect of approaching traffic as seen from different distances from the edge of the main carriageway, and illustrates the advantages of the more remote distances. From these positions not only can the forward movement of the approaching vehicles be better appreciated, but it is also possible to see the extent of the gaps between them in a way which is impossible from the close position. These diagrams suggest that a minimum lateral distance of 100 ft is desirable. At this point it is essential that traffic approaching the intersection from the minor road should be travelling at reduced speed so that the driver has his vehicle well under control during the period in which he is deciding upon his course of action. It remains to be decided what that speed should be.

As traffic approaching the intersection from the minor road and having to turn right must be able to stop if necessary at the edge of the main-road carriageway, its speed at a point 100 ft from that carriageway should not be more than about 20 m.p.h. It is, therefore, reasonable to assume this figure as the design speed for vehicles making the left turn, as all vehicles, whether turning left or right can be assumed to be most safely travelling at a uniform speed at this point. The minimum desirable radius of entry into the acceleration lane therefore becomes 50 ft, and the turning speed 20 m.p.h. Fig. 15, Plate 1, shows the observed positions of vehicles on an acceleration lane laid out to Ministry of Transport standards,[3] from which it can be seen that the lane is used effectively by less than 20% of the turning traffic and it is clear that a more generous provision is necessary in respect of both minimum radius and width of lane, if it is to be used.

The length of acceleration lane to be provided depends upon the design speed of the main road, and on the speed at which it is desired that vehicles should enter the main road stream. On an all-purpose road, with substantial variations in the speed

f traffic travelling on it, lower speeds of entry may safely be assumed than on a notorway, where uniformly higher speeds are likely to be met. Fig. 16, Plate 1, hows the actual speeds of vehicles past an intersection on a trunk road on a section which has a design speed of 60 m.p.h., from which it can be seen that a vehicle ntering at 35 m.p.h. does so at a speed within 5 m.p.h. of 44% of the traffic on the oad and within 10 m.p.h. of 72% of the traffic. It has been suggested in America hat a speed differential of 10 m.p.h. should apply for merging at acceleration bays. t is therefore considered that for intersections on all-purpose trunk roads an entry peed of 35 m.p.h. may be regarded as sufficient, although the speed of entry to notorways may need to be higher.

The length of lane necessary to provide for vehicles accelerating from 20 m.p.h. to 35 m.p.h. may be assumed to be about 400 ft on the basis of the observed acceleration of popular makes of motor cars shown in Fig. 19, Plate 2.

The actual shape of the acceleration lane may be in one of the forms shown in Fig. 20, Plate 2. Investigation into the paths of emerging vehicles carried out in America uggests that drivers tend to make their own transition, and that in general terms hose achieving higher speeds for the turn tend to swing farther out into the road han do those entering more slowly.[12] From this investigation it would appear that Fig. 20a is the more desirable shape of lane from the point of view of economy and of ncouraging drivers to follow the path most beneficial to them. When considering he nature of the actual point of entry, it is important that entering vehicles should do so as nearly parallel to the main carriageway as possible, and for this reason Fig. 20b is not so satisfactory as the kerb line shown in Fig. 20a. As in the case of the deceleration lane, however, it is desirable that observation should be made on the behaviour of traffic on possible alternative layouts in order to achieve the most efficient and economical design.

(2) *Carriageway marking*

As the left-turning vehicle approaches the intersection from the minor road it should have its path clearly defined by a central white line, and reflecting studs. The edge of the main carriageway should also be defined both for the through traffic and for the benefit of the emerging vehicle in time of fog. As in the case of the deceleration lane, the intermittent white line should preferably consist of 6-ft lengths, 6 in. wide, at 12-ft intervals.

(3) *Signing*

A driver approaching an intersection on a minor road should be given advance warning of the intersection, and advance direction to the route he requires. It is customary for the warning to take the form of a Slow or Halt Major Road Ahead sign, but in so far as the left-turning vehicle is required to enter the major road at speed, neither sign is appropriate, and it is suggested that the advance direction sign should be so designed as to give the driver a clear indication that he is approaching a main road, as illustrated in Fig. 22, Plate 2. In addition, an intersection at which the approaching driver has adequate vision in both directions along the main road does not require to be furnished with an advance warning sign because the character of the road should be made apparent by the traffic on it; if there is none, the warning sign is unnecessary. The amount of vision necessary for this purpose is discussed below. In parenthesis, there is in Great Britain a tendency to erect warning signs to safeguard the highway authority from criticism, after an accident, that no warning was provided. It should, however, be axiomatic that warning signs are provided only

when some action which is not apparent to drivers is required of them, and by this criterion warning signs at intersections should not be required in the circumstances outlined above.

The siting of the advance direction sign should be such that drivers have sufficient time to reduce speed in gear to that required to negotiate the intersection safely. On the basis of a speed of 20 m.p.h. at a distance of 100 ft from the main carriageway, the sign should be erected at a distance of about 500 ft from the edge of the main carriageway for a normal approach speed of 50 m.p.h., and 300 ft for a normal approach speed of 40 m.p.h.

(4) *Visibility*

The dangers of a confined width to the approach road are apparent. At the site of the advance direction sign on the minor road, a sufficient length of the main road should be visible to the driver to enable him to appreciate what he is approaching. It is suggested that the amount should be equal to that subtended by normal forward vision, namely, about 10° from the driver's position. As the vehicle moves towards the intersection the driver's vision to his right should steadily increase to the maximum at the point at which he enters the turning movement, and to the left it should enable him to see the shape of the curve he has to follow for a sufficient distance ahead to enable him to proceed with a steady reduction of speed to a minimum at the point of entry into the 50-ft-radius curve, without the need for more than moderate braking. The maximum visibility distance to the emerging driver's right is governed by his need to be able to see from a point 100 ft from the edge of the main carriageway a vehicle approaching along the main road at a speed equal to the full speed value of the road sufficiently far off for the emerging driver not to be taken by surprise by the arrival of this vehicle simultaneously with himself at the end of the acceleration lane. Assuming that the emerging driver accelerates from 20 m.p.h. to 35 m.p.h. in the length of the acceleration lane, the time consumed is about 10 sec. During this period, the main-road vehicle travelling at 60 m.p.h. will have covered 900 ft, and this can be taken to be the minimum sight distance measured from the end of the acceleration lane. The situation is illustrated diagrammatically in Fig. 23, Plate 2.

Right-out movement

Requirements

Right-handed movements are the most dangerous of those occurring at intersections, and right-out manœuvres cause about 20% of the accidents occurring at three-way junctions. Collisions with the on-coming and following vehicles occur in a proportion between $1\frac{1}{2}:1$ and $2:1$. The difficulty of the movement is that the emerging vehicle has to cross both streams of traffic on the main road at low speed to arrive at its correct position on the far side, and even if he is provided with unlimited vision the emerging driver has to assess the distance and speed of approaching vehicles coming from opposite directions, so that both cannot be in his field of view simultaneously.

The extreme alternative layouts that could possibly deal with this situation are shown diagrammatically in Fig. 26, Plate 2. Fig. 26a shows the orthodox right-angled entry in which the emerging vehicle executes the turning movement entirely on the main carriageway, whilst Fig. 26b illustrates the modified Bennett junction in which the vehicle emerges more nearly parallel to the main road traffic, having executed part of the turning movement in the mouth of the intersection.

The dangers associated with the layout illustrated in Fig. 26a are that the emerging hicle forms an obstruction to the main road traffic for a longer period than in the nction shown in Fig. 26b, and that, if the driver becomes involved in a collision, it likely to be a severe one. Compared with the more orthodox layout, the Bennett nction has the advantage in that the emerging vehicle enters the main road liquely to the traffic, and avoiding action, if necessary, is easier, and collisions, they occur, are likely to be less severe. However, this layout suffers from two awbacks. One is that the emerging vehicle enters the main stream on its off-side, d the following driver is in a quandary as to whether to overtake on the near- or f-side, and the other is that in this position the emerging driver is unable to see the llowing vehicle, as it is approaching on his blind side. Although modified Bennett nctions have been constructed experimentally, it is unfortunate that, so far as the uthor is aware, none has yet been provided at a junction having a substantial volume traffic executing this manœuvre, and no figures are therefore available for the haviour of traffic and accidents resulting from such a layout.

It would seem that the logical solution lies between the two alternatives quoted oove, which, whilst encouraging the emerging vehicle to enter the main road at an blique angle, should ensure that the angle is not so great as to make the driver ind to following traffic on the main road. Detailed arrangements for achieving is are discussed later.

It would also seem that the emerging vehicle should as soon as possible take up s correct position on the near side of the road, so that following vehicles are in no oubt as to which side to overtake. To encourage this, and to provide an area in hich the entering vehicle can safely accelerate to the speed of traffic in the main ream, it is suggested that an acceleration bay should be provided on the far side f the main road.

The basic requirements for the right-out movement then become:—

(1) Adequate vision of the main road for the driver approaching on the minor road, so that he is in no doubt as to the character of the main road.
(2) "Channelization" of the emerging vehicle so that it is encouraged to reduce speed before entering the main road, together with unmistakable definition of the near side of the main carriageway.
(3) Adequate vision along the main road in both directions so that the emerging driver can be given ample opportunity to assess the situation before emerging.
(4) Encouragement to the emerging driver to place his vehicle so as to enter at as small an angle as possible, consonant with ability to see following traffic from the point of entry.
(5) Provision of an acceleration bay on the far side of the road from the intersection so that the emerging vehicle does not occupy the main road while accelerating, and to indicate clearly to the following driver that he should overtake on the off side.
(6) Definition of the through lanes.

rovision

1) *Layout*

Because, unlike left-turning movements, the right turn may involve collisions with ehicles moving at right-angles to one another, which consequently may be more erious than those in which the vehicles are more nearly parallel to each other, it is

desirable that the speed of entry of emerging vehicles should be checked. Appropriate layout is the most satisfactory method of ensuring that this occurs, because the enforcement of mandatory signs presents a demand for supervision by the police which, in most areas, cannot be met. The authorized Ministry of Transport design compels drivers to slow down in order to negotiate an island, as shown in Fig. 25b, Plate 2. Where the major road has one carriageway only, and the traffic on the minor road is light, the authorized design accepts the principle of direct approach to the main road as shown in Fig. 25a, and from the point of view that simplicity of layout is always to be preferred if it can be made to achieve the desired object, this layout is more satisfactory.

It may be possible to reduce the speed of the minor-road vehicle when approaching the intersection by some other feature of layout, and it is suggested that if the lane of entry is limited in width to the minimum necessary for the normal vehicle to make the turning movement safely, it may have the desired effect. For this purpose it is suggested that the entry should be confined as shown in Fig. 17, Plate 1. It will be noticed that the island to the driver's right is marked on the carriageway and is not raised and kerbed. The advantage of this method is that the central white line and reflecting studs on both right- and left-turning drivers' routes can continue along the off side of their respective lanes, and the absence of raised kerbs allows latitude of movement for the abnormal vehicle. The actual shape of both islands is governed by the desirable angle of approach of the minor-road vehicle. It has been suggested that this should be sufficiently acute to the main road to allow the emerging vehicle to execute the turn comfortably while accelerating, at the same time allowing the driver adequate vision to his left. Unfortunately, from many vehicles on the road today, in particular lorries and vans having entirely enclosed bodies, the range of view to the driver's left is limited to little more than 5° beyond the normal to the driver's front, and this feature must be regarded as a grave shortcoming in design from the safety point of view. Having regard to the large number of vehicles of this type on the roads, it would appear that drivers should not be encouraged to turn through a greater angle than 5° before entering the main carriageway.

When entry has been made, it is then necessary to encourage the driver to take up a position in the slow-moving or near side, of the main carriageway and for this purpose an acceleration lane as shown in Fig. 17, Plate 1, is suggested.

The width of the lane at the point of entry should be at least 15 ft, so that the emerging vehicle has complete protection from the main-road traffic at the point of lowest speed, and the length of the lane should be sufficient to allow for acceleration from 20 m.p.h. to 35 m.p.h. before the vehicle enters the main stream.

As in the case of the left-out movement, when the emerging vehicle reaches the end of the acceleration lane and enters the main stream, a conflict may occur with the following vehicle on the main road. Here again it is suggested that the following vehicle has a greater opportunity of avoiding a collision than is possible in the orthodox layout.

(2) *Carriageway marking*

The carriageway marking necessary for this movement is the definition of the approach lane from the minor road, and the definition of the near and far sides of the main carriageway. It is of the utmost importance that the near-side of the main carriageway should be marked in such a way that the driver cannot miss it, even in the most adverse conditions of visibility, and emerge prematurely, and it is therefore suggested that an intermittent white line at least 12 in. wide should be

rovided across the opening, to overcome the foreshortening effect to a driver ap-roaching a transverse line. The far side of the main carriageway can be marked ith intermittent lines 6 ft long and 6 in. wide at 12-ft intervals.

) Signing

The suggested sign is illustrated in Fig. 22, Plate 2. Although the driver of the ehicle turning right-out from the minor road may be required to stop in the face f on-coming traffic on the main road, it should be sufficiently obvious when and here this is necessary for no other form of warning to be erected, and any tempta-ion to provide additional warnings in these circumstances should be firmly resisted.

) Visibility

The advantages of a good range of vision over the main road to a driver turning ft from the minor road apply with greater force to the right-turning driver, because is of the utmost importance that he should not emerge prematurely in the face of pproaching traffic, and the sight of the main road and the traffic upon it will be a ore compelling warning than any advance sign. It may be said that provision of isibility on what will be considered by some to be a lavish scale is an extravagance land use; but the use of land for this purpose at important intersections is amply ustified in view of the high accident rate common at such sites and the much greater reas which are necessary for more elaborate junctions involving the provision of y-overs. Moreover, it will be seen that the additional area of land required for one ach intersection at mile intervals is equivalent to no more than 3 ft of additional verall width on the intermediate highway.

Therefore, the amount of vision to be provided should be governed not by the area f land required, but by the need of the occasion, and although that need is common the major and minor road drivers approaching the intersection, it is primarily pon the latter that the safety of the encounter depends. If it is argued that the nd can be saved by the judicious use of warning signs, the answer lies in the acci-ent rate at blind intersections provided with all the appropriate warnings, of which xamples are given in Table 7.

TABLE 7

Site	Signs provided	Months	Accidents				
			Fatal	Serious	Slight	No injury	Total
eddington	Halt Advance Direction	120	1	2	6	6	15
iddleton Stoney	Halt Advance Direction	120	—	1	3	12	16
hinnor	Halt Advance Direction	108	1	2	2	6	11

The amount of vision to be provided for a driver approaching the major road from he minor road should be sufficient for him to be able to stop comfortably before eaching the main-road carriageway from any position, when a vehicle on the main oad comes into view. Alternatively, he should be able to see far enough along the ain road to be able to achieve the far side of the main carriageway without any isk of interrupting the main-road traffic flow. It may be said that to provide ample

vision may encourage the emerging driver to do so at too great a speed to be able to stop in the event of his failure to judge the distance and speed of the approaching traffic on the main road. It is undoubtedly true that this is the prime cause of collisions involving an emerging vehicle, and it therefore follows that every possible facility should be provided for the driver to be able to judge these two vital factors. But as has already been pointed out, the farther a driver is removed laterally from the main road, the better he is able to judge the speed and distance of the approaching traffic on it. If he is given the opportunity, and is at the same time made aware of the importance of the main road by sight, and by the other aids already referred to, only the most wantonly reckless driver will emerge without stopping in the face of on-coming traffic.

Right-in movement

Requirements

This movement is outstandingly the most productive of accidents of all those occurring at three-way intersections, and may account for as much as 70% of the total (see Figs 3 and 4). In these accidents the turning vehicle is involved in collisions with the following and on-coming vehicles in proportions between 2:1 and 3:1.

An analysis of the accidents which occur shows that in those in which the following vehicle is involved, the driver of that vehicle attempts to overtake the turning vehicle on the off-side while the movement is taking place, and in those involving the on-coming vehicle, the turning driver fails to appreciate the distance and speed of approach of that vehicle. Bennett[1] has shown that the risk of collision and the likelihood of its being a severe one are greater if the junction is a right-angled one because the turning vehicle is, in these circumstances, compelled to make an acute turn of small radius, thus taking the following vehicle by surprise, while at the same time presenting the maximum obstruction on the main road when in the broadside position. Moreover, the time absorbed in crossing the path of the on-coming traffic will be greater if the driver is required to execute a right-angled turn than is necessary for an oblique crossing, and the safe gap in the traffic flow is correspondingly greater.

It is evident that to prevent a collision with the following vehicle not wishing to make the turn, the latter should be provided with a passing lane on the near-side of the turning vehicle, and it is indeed not surprising that when not so provided, collisions should occur. On a two-lane road, having a speed value of 60 m.p.h. or more as is common on many main roads, the driver may find himself confronted with a stationary vehicle in his path with, in the event of a simultaneously on-coming vehicle, no carriageway space in which to take avoiding action, and, if he has failed to appreciate the situation in time, insufficient distance for braking. The Ministry of Transport has recognized the need for some carriageway widening to meet this contingency, as illustrated in Fig. 25b, Plate 2, but it is remarkable that having regard to the very high accident rate resulting from this situation and the very simple and even obvious remedy, apparently not a single intersection in Britain has been provided with this feature. On three-lane carriageways the danger is theoretically not so acute, but the half-width of 15 ft is in practice insufficient on a fast road to accommodate a passing vehicle in addition to the vehicle waiting to make the turn, and this is borne out by the accident statistics for intersections on such roads, of which an example is shown in Table 8.

Furthermore, the addition of a passing lane is unlikely to prove successful in practice, unless the route to be followed by both turning and through traffic is clearly defined on the carriageway and by appropriate signs so that the drivers of both

hicles are confident of their own and each other's course of action. This factor is phasized by the number of motor-cycles involved in accidents in the example oted.

The basic requirements for the right-in movement thus become:—

(1) Clear indication to the turning driver of the route he has to follow.
(2) Facilities and encouragement to the following driver to pass on the near-side of the turning vehicle.
(3) Discouragement to the following driver to overtake the turning vehicle on the off-side.
(4) Provision of safe harbouring area for the vehicle waiting to make the turn.
(5) Provision of an oblique crossing for turning vehicles in preference to a right-angled turn.

ovisions

Layout

The primary requisite to meet the needs of this movement is the provision of an ded carriageway width to accommodate both the turning and passing vehicle multaneously.

In determining the width and length of the passing lane it must be borne in mind at it is to be used by the main-road through traffic, and should therefore be designed accommodate that traffic travelling at its normal speed, and should not offer any striction either in lane width or curvature which would be likely to discourage the iver of the through vehicle from using it. Indeed, for success, it is essential that rough traffic should use the passing lane on all occasions, whether or not a turning hicle is present, as only in this way can a pattern of behaviour be formed which ll become natural and automatic. It follows that the width of the passing lane ould be equivalent to the lane width on the adjoining sections of road. The length the passing lane will be determined by the length of the turning lane, and the rvature of the approaches.

The length of the deceleration lane for the turning vehicle should be sufficient to ow the driver to enter the lane at normal speed and come to a stop, if necessary, the end of the lane without difficulty. Fig. 18, Plate 2, shows the braking distance quired for various coefficients of friction, from which it will be seen that at an sumed coefficient of 0·40 a braking distance of 160 ft is required for a speed of 45 p.h., and this may be taken to be the length of lane required, as it may be sumed that a driver travelling at more than 45 m.p.h. will have reduced speed on ssing the advance direction sign of the intersection. The exact siting of this sign ll be discussed in a later section but it should be situated at least sufficiently stant from the beginning of the deceleration lane to allow the vehicle to reduce eed in gear from the full speed value of the road to 45 m.p.h. If the former is 60 p.h., this distance becomes about 600 ft. The radius of the curvature of the passing ne should be sufficient to avoid any feeling of discomfort on a normal camber, as is not practicable to provide superelevation in this lane without leading to ainage difficulties and a minimum radius of 5,000 ft is considered desirable.

Carriageway marking

The segregation of turning traffic from the through traffic can be achieved only th the aid of carriageway marking which can also be used to prescribe the no-overking zone. The suggested method of marking is illustrated in Fig. 17, Plate 1, m which it will be noted that guidance can be given to both through and turning

traffic by the provision of arrows on the carriageway. The point at which t turning traffic should cross the opposing stream is indicated by a 12-in. line mark obliquely across the end of the deceleration lane, and it is suggested that a measu of this sort is of great assistance to the turning driver in fog by locating the exa point at which to make the turn. In order to protect the turning vehicle fro on-coming traffic while stationary, it is suggested that the oblique striping of t carriageway should be continued over the triangular no-man's-land between the tw opposing through lanes, otherwise a large expanse of unmarked carriageway m tempt the on-coming driver to overtake. The striping will also accentuate the poi of turning, as it is unlikely that the driver will run far on to this area without bei aware of it, even in the most adverse conditions of visibility.

A continuous white line and closely spaced reflecting road-studs at the exit from t main road will guide the turning driver into his correct route.

(3) *Signing*

The general principles governing the nature and siting of advance direction sig apply equally to the sign suggested for this movement. The sign can well be us to indicate the path to be followed by both through and turning traffic, as shown Fig. 27, Plate 2.

(4) *Visibility*

If the intersection is designed to provide adequate visibility for each of the ot movements which take place, it will possess a sufficient standard of visibility to me the requirements of the right-in movement, as a vehicle executing this manœuvre required to cross one stream only on the main carriageway at a point where vision limited only by the alignment of the through road beyond the intersection. T splay provided in the boundary line of the minor road approaching the intersecti should remove any possible restriction on vision at the point where the vehi turning right-in has to cross the right-out stream from the minor road, particula bearing in mind that speeds at this point will be restricted to about 20 m.p.h.

The completed design

Fig. 17, Plate 1, shows the completed design of a three-way intersection of tw lane roads which incorporates all the features to which reference has already be made. Fig. 21, Plate 2, shows the same principles applied to the juncti of a three-lane road with a two-lane road, and Fig. 24, Plate 2, the junction of du carriageways with a two-lane road. It will be noted that in each case the layout the minor road is identical, and this is considered to be an important factor, if pattern of driver behaviour is to be established. The variations in the main-ro layout are consequent only on the differing widths of carriageway, and the actu movements expected of drivers are identical in each case. It will be seen that in t dual carriageway example a central reservation of 30 ft has been provided, and t is regarded as a minimum at an important intersection if vehicles turning right-o are to be safely harboured while waiting to make the turn. It has to be remember that on dual carriageways this movement is more difficult than on two-way roads the sense that the turning driver may have to cross two streams of traffic instead one, and, as the speed of through traffic is likely to be high, full protection the stationary vehicle in the central reservation is essential.

The cost of constructing any one of the layouts shown in Figs 17, Plate 1, a

TABLE 8.—TYPICAL ACCIDENT STATISTICS FOR AN INTERSECTION

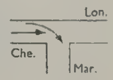
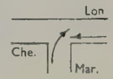
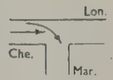
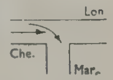
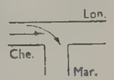
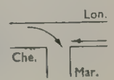
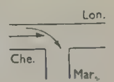
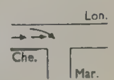
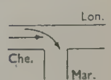
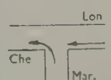
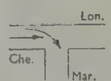
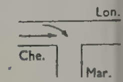
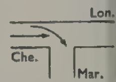
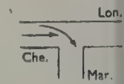
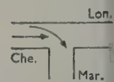
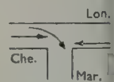
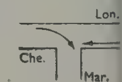
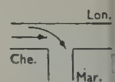
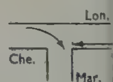
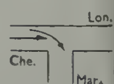
Date	Time	Weather	Injuries		Description	Manœuvres of vehicles
			To persons	Degree		
3.49	2310	Fine, dark	Rider and passenger of motor-cycle combination	Serious	Motor-car proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, turned right and following motor-cycle combination collided.	
5.50	2320	Fine, dark	Rider of Motor-cycle	Serious	Motor-cycle proceeding along A.40 in the direction of Cheltenham. Upon reaching 1st Marston turn, motor-car turned out in the direction of London and collided.	
.5.49	2055	Fine, day	No injury		Lorry proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, turned right and following motor-car collided.	
.8.50	2130	Fine, dark	Rider of motor-cycle	Slight	Motor-car proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, turned right and following motor-cycle collided.	
5.46	2100	Fine, day	Rider of motor-cycle	Slight	Motor-car proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, turned right and following motor-cycle collided.	
6.46	2215	Rain, dark	Rider of motor-cycle	Slight	Motor-car proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, turned right and on-coming motor-cycle collided.	
3.7.46	1800	Fine, day	Rider and pillion-passenger of motor-cycle	Slight	Lorry proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, turned right and following motor-cycle collided.	
1.4.52	2030	Wet, dark	Rider and pillion-passengers of both motor-cycles	Slight	Motor-car proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, halted, prior to turning right, following motor-cycle halted, and following motor-cycle collided.	
11.52	0745	Wet, day	Rider of motor-cycle	Serious	Motor-car proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, turned right and following motor-cycle collided.	
1.4.46	1715	Fine, dark	No injury		Lorry proceeding along A.40 in the direction of Cheltenham. Upon reaching 1st Marston turn, lorry turned out in the direction of Cheltenham and collided.	
7.55	2040	Fine, day	No injury		Motor-car proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, turned right and following motor-car collided.	

TABLE 8.—*continued*

Date	Time	Weather	Injuries		Description	Manœuvres of vehicles
			To persons	Degree		
11.11.53	1845	Fine, dark	No injury		Public service vehicle proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, halted, prior to turning right, and following lorry collided.	
9.12.53	0710	Fog, dark	Rider of motor-cycle	Serious	Motor-cycle proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, turned right and following motor-cycle collided.	
24.12.53	1130	Fine, dark	No injury		Motor-car proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, turned right and following motor-car collided.	
27.1.54	1830	Fine, dark	Rider of motor-cycle	Slight	Motor-cycle proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, turned right and following motor-car collided.	
23.3.54	2230	Fine, dark	Rider of motor-cycle	Fatal	Motor-car proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, turned right and following motor-cycle collided, then swerved, and collided with on-coming lorry.	
21.5.54	1730	Fine, day	Rider and pillion-passenger of motor-cycle	Slight	Motor-car proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, turned right and collided with on-coming motor-cycle.	
30.7.54	1740	Fine, day	Driver of motor-car	Slight	Motor-car proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, turned right and following motor-car collided.	
2.12.55	0820	Fine, fog, day	Rider of motor-cycle	Serious	Lorry proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, turned right and on-coming motor-cycle collided.	
8.12.55	1845	Fine, dark	Rider of motor-cycle	Serious	Motor-car proceeding along A.40 in the direction of London. Upon reaching 1st Marston turn, turned right and following motor-cycle collided.	

Figs 21 and 24, Plate 2, will depend to such an extent upon the local characteristics of the site that it may be misleading to give details. However, as a basis for comparison it may be said that the basic cost of conversion of a simple junction illustrated in Fig. 25a, Plate 2, to that shown in Fig. 17, Plate 1, is about £3,500, and the equivalent figure for the three-lane road illustrated in Fig. 21, Plate 2, is about £2,500. The cost of providing the junction on dual carriageways as illustrated in Fig. 24, Plate 2, is about £6,000, which may be compared with a cost of £5,000 for the orthodox layout illustrated in Fig. 25b, Plate 2. If the designs were, in fact, to prove satisfactory in operation, and were to offer a substantial reduction in accident rate, these amounts would not seem to be an unreasonable expenditure at the many intersections of orthodox design which are at present accident black-spots.

It must be emphasized that it cannot be claimed for this design, or indeed for any design, that it is of unlimited capacity. The absence for so many years of an effective programme of road construction to match the increasing needs of traffic in Great Britain has undoubtedly had the effect of depressing standards of design, and there is a danger that intersections even when improved may not cater safely and adequately for the volumes of traffic which use them at present, or for the even greater volumes which will use them in the near future. American experience, as illustrated in Table 9,[13] suggests that the accident rate at three-way intersections is affected not so much by the volume of through traffic as by the percentage of turning traffic, and it would seem that when this figure exceeds 10%, serious consideration should be given to the provision of grade separation. Comparable figures are not available for the three- and four-lane roads, but the accident rates at all intersections (including cross-roads) on such roads are about five times higher at intersections carrying more than 10% crossing traffic than the rates at intersections carrying less than

TABLE 9.—ACCIDENT RATES AT THREE-WAY INTERSECTIONS

(on two-lane roads per 10,000,000 vehicles)

Turning traffic	0 to 4,900 vehicles per day	5,000 to 9,900 vehicles per day
0 – 9%	1·5	1·3
10% or more	5·4	6·3

10%.[13] Although the rates may not vary substantially as a result of the increase of through traffic, a highway authority would no doubt be influenced by the knowledge that if the traffic doubles and the rate remains constant, there are in fact twice as many accidents.

In selecting sites at which to apply the design suggested in this Paper, those at which the turning traffic amounts to about 10% of the total come most readily to mind. These sites are, in practice, accident black spots, and no plans exist for their improvement such as have been prepared for intersections carrying higher volumes of turning traffic, for which roundabouts or fly-overs are envisaged as soon as funds are available. It would be of interest to study the effect on traffic behaviour and accident rates of the implementation of the design at a selected number of such sites.

Acknowledgements

The Author wishes to express his indebtedness to Mr R. W. H. Mellor, M.C., M.A., A.M.I.C.E., County Surveyor of Oxfordshire, for permission to prepare the Paper, and to the members of his staff who undertook the experimental work and the preparation of the drawings, particularly to Mr R. Young and the Road Safety Section. He is also indebted to the Director of Road Research for permission to reproduce information prepared by the Road Research Laboratory, and for the loan of the Radar Speedmeter. Finally, the Author would like humbly to pay his tribute to the memory of the late Col. G. T. Bennett, O.B.E., B.Sc., M.I.C.E., from whose work and inspiration the whole study of intersection design in Great Britain springs.

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The Paper, which was received on 10 January, 1956, is accompanied by twenty-eight sheets of diagrams, from which the Figures in the text and folding Plates 1 and 2 have been prepared.

Discussion

The Author introduced the Paper with the aid of a series of lantern slides.

The Chairman, when proposing the vote of thanks to the Author, said he had always felt that one of the two main attributes of a good engineer and certainly of his activities was that he should explore the unknown and cast a good deal of doubt on the known. He thought that the Author had shown how much doubt could be cast on the known—whether they all agreed with him was another matter altogether. He could not help feeling himself that many of the conditions which the Author had outlined applied to

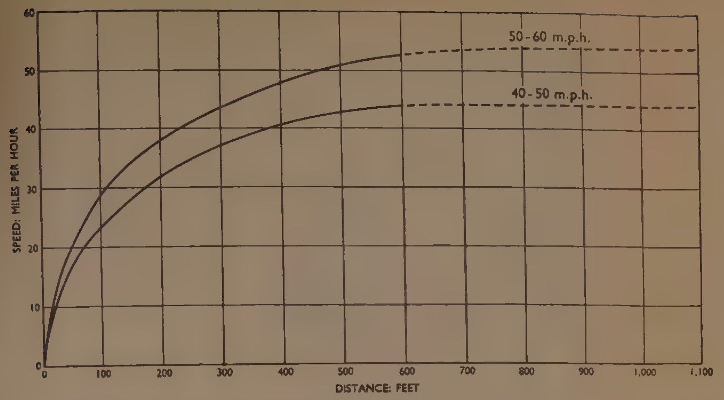


FIG. 7.—OBSERVED SPEED AND DECELERATION OF VEHICLES APPROACHING A STOP SIGN

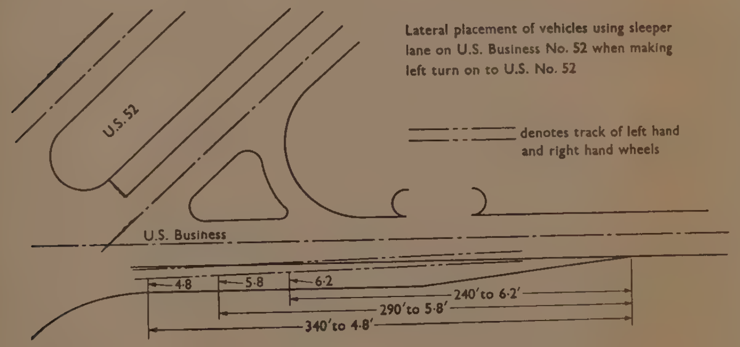


FIG. 8.—DRIVER BEHAVIOUR ON A DECELERATION LANE

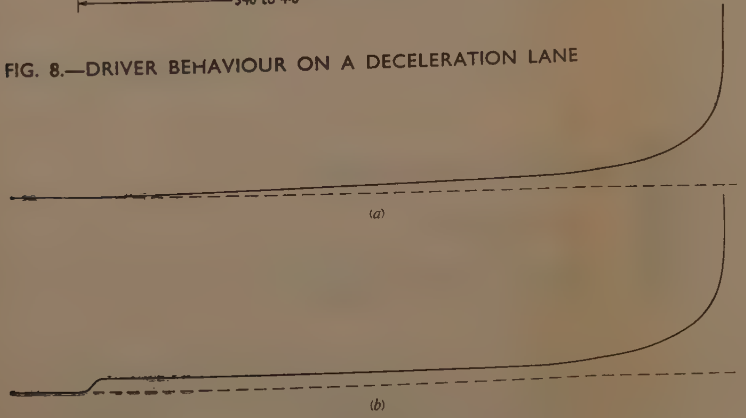


FIG. 9.—ALTERNATIVE SHAPES FOR DECELERATION LANES

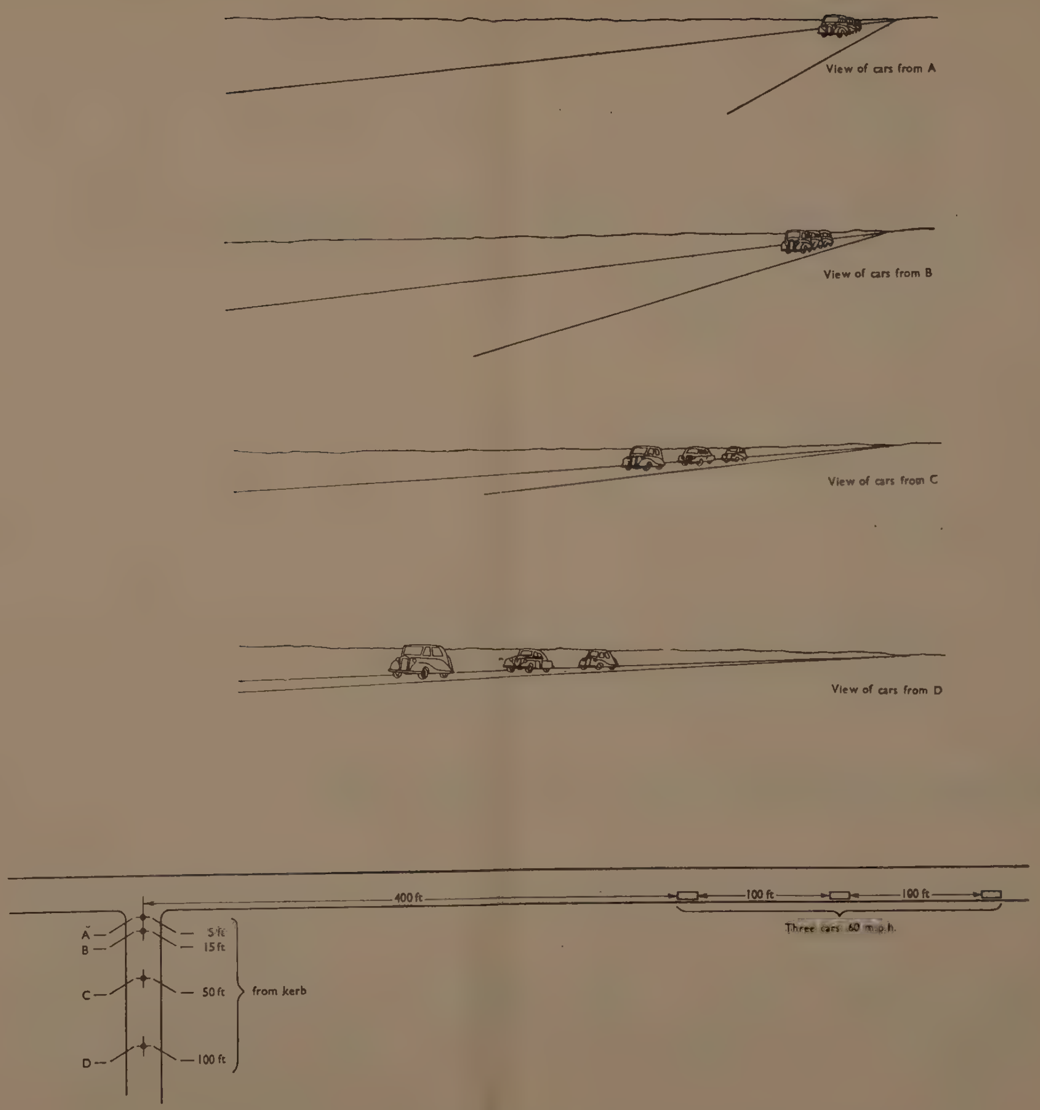


FIG. 10.—ASPECTS OF MAIN ROAD TRAFFIC AS SEEN FROM T JUNCTION

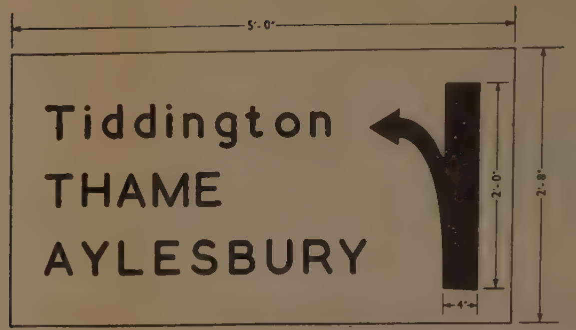


FIG. 11.—SUGGESTED ADVANCE DIRECTION SIGN FOR LEFT-IN MOVEMENT. ALL LETTERING TO BE 4 IN.

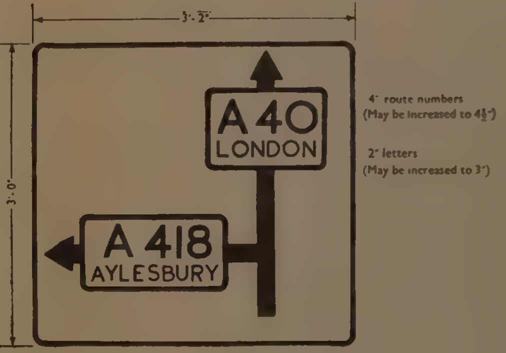
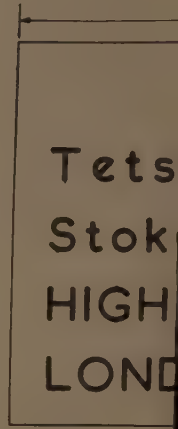
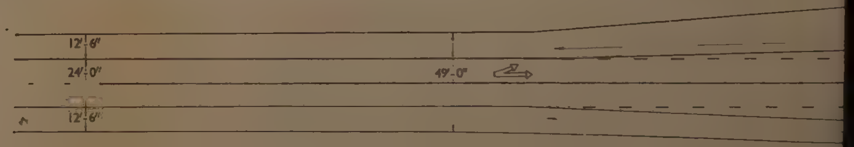


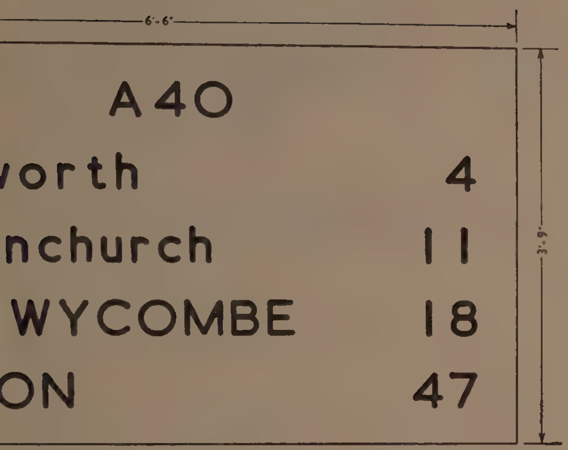
FIG. 12.—AUTHORIZED ADVANCE DIRECTION SIGN FOR LEFT-IN MOVEMENT



FIG



William Clowes & Sons, Limited: London.



3.—SUGGESTED CONFIRMATORY SIGN

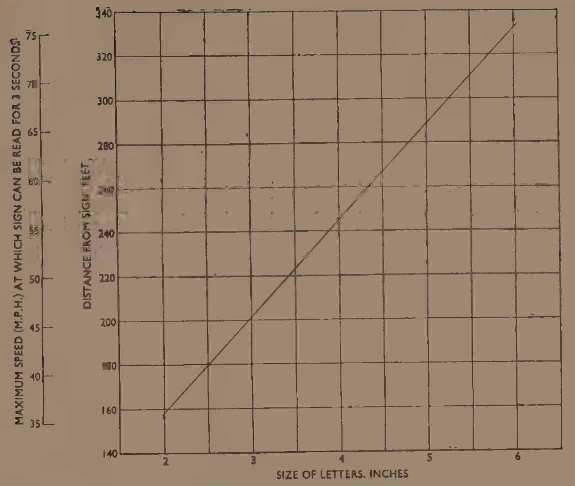


FIG. 14.—MAXIMUM SIGHT DISTANCES FOR PERSONS WITH NORMAL VISION IN AVERAGE DAYLIGHT

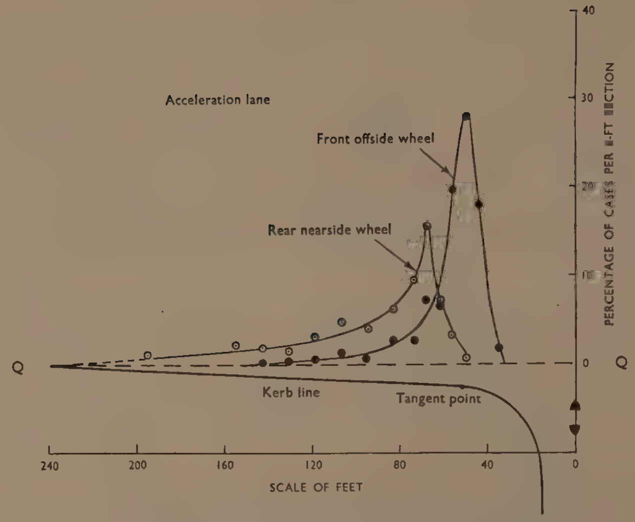


FIG. 15.—DISTRIBUTION OF LEADING- AND TRAILING-WHEEL POSITIONS ON LINE QQ, SHOWING USE OF ACCELERATION LANE

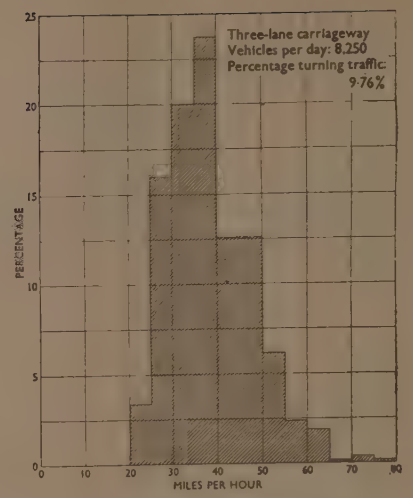


FIG. 16.—FREQUENCY DISTRIBUTION OF VEHICLE SPEEDS

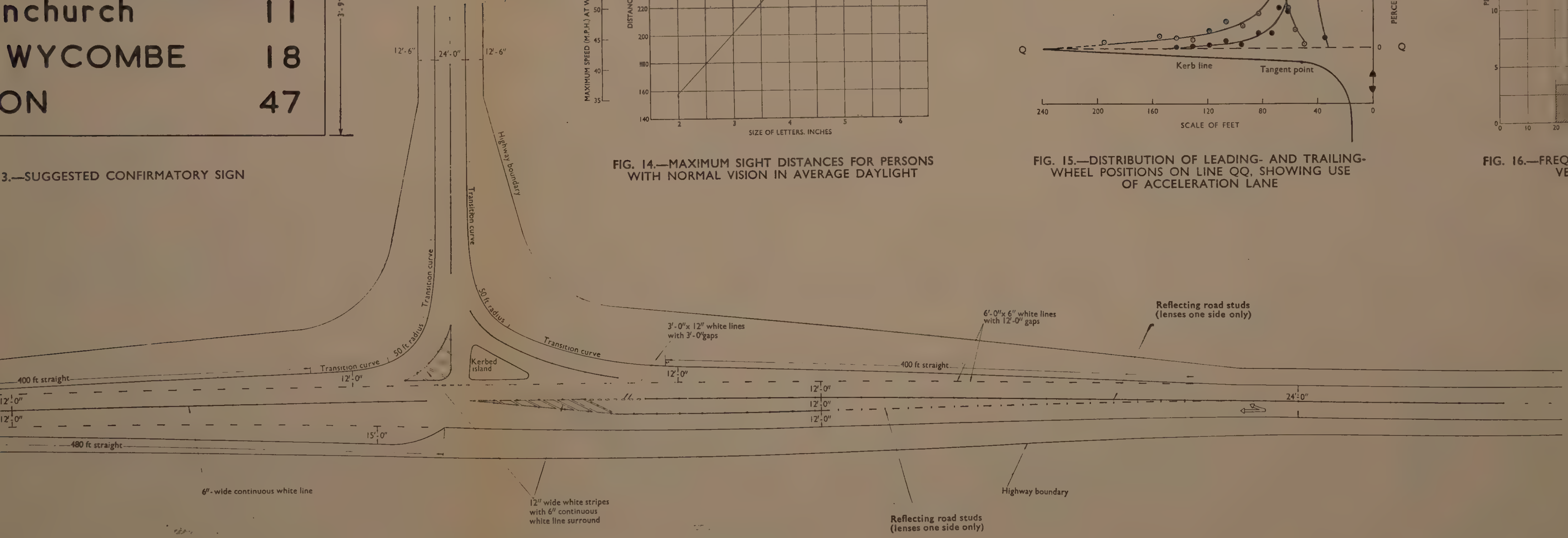


FIG. 17.—SUGGESTED LAYOUT FOR RURAL THREE-WAY INTERSECTION ON A TWO-LANE ROAD

KENNETH SUMMERFIELD

ad that was congested with traffic. There were many roads where it seemed pointless go in for such elaboration. Speaking for himself, he had yet to appreciate the function, r instance, of an acceleration lane on a two-lane carriageway. It appeared to him that was more dangerous in that connexion than it might be safe. On a three-lane rriageway he could appreciate it fully.

Mr H. S. Andrew (County Surveyor, Middlesex) observed that on p. 336 the Author rote of deceleration lanes and the turning speed on going in on the left-hand turn and coming out. He did not doubt the safety of the turning speed of 20 m.p.h., but he ther doubted the comfort of it. He was not sure that a speed of 20 m.p.h. to take a)° corner, even though there was a 50-ft radius, would be comfortable. Many drivers nded to decelerate to less than that speed and tried to take the bend while accelerating om 15 to 20 m.p.h.

Had the Author considered the desirability of omitting kerbs and substituting a hard oulder on some bends on the turn-in and turn-out?

On the question of signs, he would agree with the omission of details on the sign on e through route. It was not necessary to know every ½ mile or so that one was on the ain road from Oxford to London, for instance; but he was rather doubtful about the nission of the route number of the side turning. In driving through the average county here there was a side turning every ½ mile leading off to perhaps a principal town and vo or three villages, there would be a number of side turnings going to the same places, nd one would be anxious to know which was the best route to take and would expect e second-class number on that route. Mr Andrew agreed entirely with the need for rger letters on the signs and for the use of the whole of the sign-board rather than onfining the place names within a box.

The complete design would perhaps appear a little complicated and disturbing to the river who was not used to it. Before they went much further on that matter, a andardized junction of that type should be adopted. The standards which were vailable needed looking at in the light of the present-day performance of the motor ehicle. Once the junctions existed in numbers, there would be nothing complicated bout them; but a driver seeing one for the first time would wonder where he ought to be he were making a right turn out of the main road.

Mr Andrew agreed that there should be a 30-ft centre reservation between twin rriageways where a right turn was likely to be made. Those who knew Middlesex would alize with what envy he spoke of a 30-ft centre reservation!

He was convinced that the Author was perfectly correct when he said that if there as enough traffic turning right, there was only one solution, namely, grade separation.

Mr W. Hadfield (Senior Engineer, Ministry of Transport and Civil Aviation) said e chief point made in the Paper seemed to be that up to the present road engineers had een working on the wrong side of the road. The Author had shown, in his full design, ve lanes at the actual junction—two for straight-on traffic, one for left turns, two for ght turns. It was not always possible to afford five lanes, but often there were three nes at a junction of a two-lane road, the third lane being given to the left-turning affic, which was much less dangerous than the right-turning traffic; it seemed that the hird lane could better be used to help the right-turning traffic. (See Fig. 26.)

The Author mentioned the importance of the contour of the deceleration lane for the

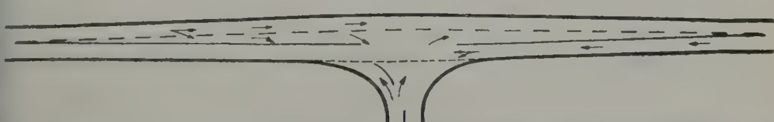


FIG. 26.—SUGGESTED LAYOUT AND ROAD MARKINGS FOR A TWO-LANE ROAD WIDENED TO THREE LANES AT A RURAL THREE-WAY INTERSECTION

left-turning traffic, and of the radius of the corner. Mr Hadfield knew a site where right-turn deceleration lane had been tried, but it was much too short and had a poo contour, and the vehicles failed to make use of it. It was important to get the right-tur contour suitable for the normal paths of vehicles, expecting that they were going to ru in as well as halt before they entered the side road.

Fig. 10, Plate 1, showing cars on a main road as seen from a side road, suggested lesson about halt signs. If one imposed "halt" control on a vehicle, the driver wa subjected to two serious handicaps. First, he was placed where he had the worst view c approaching traffic to judge its speed and, secondly, his speed differential with the main road traffic was made as bad as possible.

Table 8, which gave an accident record of a junction, suggested two possible ways c solving its accident problem. One could have the sort of expensive designs which ha been discussed; but since only one car was involved in an injury accident and all th rest were motor-cycles, perhaps some restriction of motor-cycle traffic was desirable.

Colonel C. H. ffolliott (County Surveyor, Hertfordshire) congratulated the Autho on getting down to a common-sense application of what had been learned from statistic

He thought it was time that the system of road numbering used in Britain was brough into line with that in other countries. In France the national routes were numbere right through, and to get from A to B it was only necessary to know the number to follow Equally, in Germany the main road system was numbered right through. He woul deprecate the dropping of the numbers; they were essential for long journeys. A drive did not want to be confronted with all sorts of place-names in which he was not intereste

In the Paper there was a reference to islands, which the Author said were to be avoide because they added to the complexity of the junction. Colonel ffolliott agreed with tha if the Author meant ordinary kerbed islands; but not if he was referring to traffic island For two or three junctions recently in Hertfordshire traffic islands were provided—tw on the main road. The carriageway had been widened from a 30-ft carriageway to giv a 22-ft width each side of the island. There were short acceleration and deceleratio lanes, and another island at the mouth of the junction road. Those had proved ver successful. A very black spot had been eliminated at Stevenage New Town, and sinc that construction there had been no accidents.

There might be some difficulty in the Author's layout with all the different types an thicknesses of marking—white lines, studs, etc. In conditions of snow or bad visibilit the markings would not be visible. Some form of lighting should be introduced a junctions, wherever possible, although that could not always be done right in the hea of the country.

There was a danger that on that side road junction where the Author showed th striped island and the kerbed island (see Fig. 17, Plate 1) a car trying to come straigh across to make the right-out turn would, at that point where it entered the main roa if it were a large van or bus, very much block the visibility of the driver wanting to mak the left-out turn.

Dr R. J. Smeed (Deputy Director (Traffic and Safety), Road Research Laborator D.S.I.R.) said it was stated on p. 359 that when the percentage of turning traffic exceede 10%, serious consideration should be given to the possibility of grade separation. O course, grade separation was desirable wherever possible, but he did not think that th proper criterion was when the proportion of turning traffic exceeded 10%. It mus depend also on the total amount of the traffic. It should depend on some combinatio of the turning traffic and the straight-through traffic—or on the number of accidents.

Referring to the cost of those junctions, Dr Smeed observed that the whole object of th new designs of intersections produced by the Author was to cut down the number c accidents, so that whether or not the junctions were worthwhile would depend on ho many accidents they saved. The Author had pointed out that in his county there wer 0·7 accidents per intersection per year. The average economic cost of an accident, makin no allowance for suffering of any sort, was about £330, so that the accidents were costin

the country about £230 per year per junction. Of course, some of the junctions would have the average number of accidents of 0·7 per year, some would have less, and some would have more; so it was apparent that at the junctions where three or four accidents took place per year, there was a strong case for spending money even of the order which the Author recommended. The Author gave figures of about £4,000, £5,000, and £6,000 for the costs of those junctions. If £1,000 a year could be saved it was clearly a good investment.

In some cases Dr Smeed considered that the Author's design could be made cheaper. The Author allowed a very long deceleration lane for vehicles turning into the side road. There were very few accidents to those vehicles, and where it was necessary to save money those might be places where it could be done. The Author also allowed very good visibility standards on the left when turning out of the junction. In that the Author was quite right and where possible it ought to be done; but where money had to be saved, that might be a case for it. On the other hand, there was one case in which Dr Smeed would like more money to be spent. In the case of the dual carriageway the Author suggested a centre reservation where a vehicle could stop, if necessary, and in that case the vehicle turning right out of the minor road could carry out the crossing of the first road and then stop and then turn into its proper lane. On single carriageways that movement was very productive of accidents; might not a centre reservation be provided to assist that movement even on the 30-ft road?

Mr A. J. A. Hanhart (Solicitor and Assistant General Manager, Royal Automobile Club) observed that on p. 344 the Author had invited some expression of opinion from motoring organizations as to the views of motorists on road numbering on signs.

The R.A.C. issued more than 230,000 route cards every year, covering 58 million miles. Mr Hanhart had asked the person in charge of the section dealing with those for his impressions, and the reply had been that there were just a small proportion of members who were strongly opposed to numbers, a small proportion who were strongly in favour of them, and with regard to the rest, on the whole they liked the numbers.

For those reasons, it was thought that the numbering should be maintained. It was of value to road users. The Ministry had helped by renumbering some of the routes so that they had become logical. For instance, a by-pass should carry the number of the main route, and the person whose route number changed should be the person who left the by-pass and went into the town.

A number on a route enabled a person to find his way easily over quite a long distance, whereas a succession of names was difficult to remember. In that connexion it was not easy for a motor-cyclist, without a pillion passenger, to read out the name of the next town. If he had a slip of paper that he could carry easily in his hand, it would be much easier for him to have numbers on it than to have a large route card with names on it.

In regard to the signs themselves, the Author had wisely pointed out how badly the space on the existing signs was used. Comparing the Ministry sign and the Author's proposed sign from a distance, it was obvious how much easier the Author's names were to see, because the Author was making good use of the space available. Mr Hanhart thought that the use of panels should be discontinued.

Mr Hanhart was critical of one point in the Paper relating to road design—the right-out movement from the side road with the acceleration lane on the nearside. If the through traffic were segregated from the turning traffic well before the junction and rejoined the other traffic after the junction, one could be quite certain that accidents would not occur at the junction. Where the driver was going to be faced with any form of complication, if the complications could be made successive rather than coincidental the driver's task would be eased. The right-out movement was not entirely satisfactory for two reasons. The first reason was that the right-in vehicle—the vehicle turning from the main road into the side road—might obscure to the fast through traffic the vehicle coming out. The driver of a vehicle coming out from the side road might think there was only one vehicle coming up to turn (e.g., a bus) and there might be a small sports car behind it which was obscured by the relative movement of the two vehicles almost until the last

moment. The second reason was that in the right-out movement the vehicle came at right-angles across the path of the through traffic. That seemed to be a very dangerous situation and one that was likely to cause a serious accident. Avoiding action at the last moment was very difficult when the vehicles were converging at a right-angle. If the vehicle coming out of the side road kept in the centre of the road and the accelerating lane were made by cutting a part of the centre reservation away, the merging could take place well past the junction, and if there were a collision because the driver coming out did not have good visibility to his nearside, at least it could be said that unless he made a sharp turn to the side the other driver could not fail to see that a dangerous situation was likely to arise if he squeezed past on the nearside. One would have to try to ensure that the vehicle turning right out of the junction did not go across to the nearside until the vehicle was well past the junction, either by making the lane almost separate or by putting a solid white line on its nearside for the first 50 to 70 yd.

Mr J. T. Duff (Senior Engineer, Ministry of Transport and Civil Aviation) commented on the visibility required for the right-turn out. On p. 353, the Author gave two criteria. The first was that the amount of vision should be sufficient for the minor-road driver to stop comfortably before reaching the main road. With an approach speed of 20 m.p.h. he would need about 50 ft back from the intersection to give the required visibility on the main road, and it would take him about 3 sec to reach the main road when he decelerated. With an approach speed of 60 m.p.h. on the main road, that meant a visibility distance of approximately 300 ft. The second criterion was that the minor-road driver should have sufficient visibility to emerge and reach the far kerb without interrupting the main flow. On a two-lane road that meant that he had to travel a distance of about 90 ft. At a speed of 20 m.p.h. that would take about 3 sec, so that again the visibility distance required was about 300 ft, which was nothing like sufficient. Observations showed that very few drivers would accept a gap as low as 3 sec in which to emerge; the average was 6 to 8 sec, giving a visibility distance of about 700 ft. It was true that the Author had actually provided 450 ft for the left-turn out, but that was not nearly sufficient for the right-turn out.

Finally, if the number of vehicles making a given turn was very small, it would probably be difficult to justify the cost of providing special facilities for them. It was possible, therefore, to simplify the design in appropriate circumstances. The example which the Author had chosen appeared to be particularly unfortunate in that respect. Although Mr Duff had not seen the junction, it was apparently a right-angled intersection, but the natural movement of traffic was that of a Y-junction, and it appeared that at that location there would be no need to make any provision at all either for the right-turn in or the left-turn out.

Dr G. Charlesworth (Head of Traffic Section, Road Research Laboratory, D.S.I.R.) felt that the results given in the Paper showed what valuable help could be obtained in the design of road layouts from traffic engineering units in highway engineering departments.

A few years ago the Road Research Laboratory, with the co-operation of the Ministry of Transport, with Mr R. W. H. Mellor and particularly with the late Colonel G. T. Bennett, had modified two junctions rather in the form of Fig. 26b, Plate 2. At both of those junctions, since the alteration from the square form had been made, they had been watching the accident records, and it appeared that the number of accidents each year had, if anything, been decreasing despite an increase in traffic, but the frequencies were so few that they could not be sure whether that was not a chance occurrence.

Observations had been made of the behaviour at those junctions, and Dr Charlesworth referred briefly to the observations which had been taken at Denham in relation to some of the proposals made in the Paper.

The Author had, indeed, quoted some of those results; for instance, he had mentioned the usage of deceleration and acceleration lanes. The results in Fig. 2 showed fairly clearly that drivers were certainly not using the deceleration lane as presumably the

designer had intended, and he agreed with the Author that further work on that matter was desirable.

The Author had given some results for the vehicles emerging from the side road turning left, using the acceleration bay. Those were given in Fig. 15, Plate 1, and referred to a square junction. With the splay-form junction at Denham, the emerging vehicles—the left-turning vehicles—seemed to follow a path with their offside wheels about 10 ft from the kerb but the average speed of those vehicles on the 100 yd or so distance leaving the junction was of the order of 10 m.p.h. slower than that of the main-road traffic, and indeed 14% of the emerging vehicles were overtaken in those 100 yd by the main-road traffic. That seemed to suggest that there should be longer acceleration lanes, at least for a junction as busy as that at Denham.

Some observations had been made of the right turn into the side road from the major road, which was a particularly dangerous movement. The speed of the right-turning vehicles was higher with the splay junction than with the square form, and those vehicles interfered much less with the straight-through vehicles; only about half the number of right-turning vehicles were overtaken on the approaches to the intersection with the splay form compared with the square form. The theory was that by having the splay form the manœuvre could be made rather more rapidly and therefore there would be fewer overtakings and less chance of accidents in overtaking; at least the first part of that theory seemed to be borne out by the behaviour.

On p. 353 it was suggested that the time taken by right-turning vehicles to cross the opposing stream would be shorter with the splay form, but at Denham it appeared that those vehicles spent rather longer in the opposing stream than with the square form. On the other hand, the drivers made allowance for that in selecting the gaps in the opposing stream into which they entered. The square exit for vehicles turning right out of a side road was desirable on visibility grounds, and indeed that was the basis of the modified Bennett design.

Unfortunately, at Denham no observations had been taken of the behaviour of those vehicles, since they were not very numerous, so that Dr Charlesworth could not comment on a factoral basis on the Author's proposal for acceleration bays on the opposite side of the road.

He agreed that it was very desirable that experiments should be made to test out the Author's proposals in actual practice on the road.

With regard to sign-posting and carriageway markings, there was some evidence from the work done at Denham that sign-posting and markings in the carriageway were desirable. After the construction of the splay-form junction, observations had been made of the movements of drivers at successive periods—a week after the opening of the junction, and 3 months and 6 months later. An attempt had been made to find out whether the drivers were making the movements they were intended to make. It appeared that most of the movements were made as intended, except the right-turning movements. In the week after the completion of the junction, about 15 to 20% of the right-turnings were being made incorrectly. Some direction arrows, 1 ft or so wide, were then put on the carriageway, and advance direction signs of a larger sort were installed, with flag signs on the island. Six months later it had been found that less than 2% of the right-turnings were being made incorrectly. No doubt part of that effect had been caused by the drivers getting familiar with the junction and learning how to drive through it, but he was sure that a large part of the effect had also been the result of the markings and signs. Dr Charlesworth thought that possibly carriageway markings should be much bigger than the Author suggested and should be placed rather nearer where the turns should be made.

Mr H. S. Keep remarked that the importance of the Paper was certainly shown by the large number of accidents which occurred at junctions.

In the introduction, there were some interesting figures about the spacing of road junctions on the various categories of road, and it was noticeable that the closer spacing occurred with the most heavily trafficked roads and the spacing increased as the traffic

fell, or at least on roads where less traffic would be expected. That was exactly the wrong way round from the point of view of avoiding accidents, and perhaps it emphasized the desirability of cutting out as many junctions as possible on what would eventually be the most heavily trafficked roads—the motor roads.

That point had, however, another bearing. In the case considered by the Author (Fig. 17, Plate 1), the overall length of the junction on which the original two-lane carriageway had been modified was about 380 yd. The Author gave the average spacing of junctions on the trunk road as about 750 yd, so that half the distance was modified. Since the spacings were not normally regular, there would probably even be overlapping in some cases. That, of course, applied only if a fairly general application of those intersections was being considered.

Towards the end of the Paper, the Author referred to the American suggestion that where there was more than about 10% of turning traffic consideration should be given to fly-overs. The Author appeared to agree with that suggestion. The Author also suggested, by implication about the speed of traffic, that his proposed junction would apply on only trunk and Class I roads, where the speed was high enough for his arguments to be material. Those two factors taken together seemed to narrow down the field of application of the junction of the type suggested. That did not mean, of course, that such junctions should not be tried out.

Although broadly he agreed with the Author's arguments, Mr Keep did not altogether like the composite result, and he was quite sure that the public would need a good deal of education before they would learn to use the junctions and the various lanes in the right way. That could be seen by the way in which drivers quite frequently got into the wrong channel even when there were arrows on the road and names as well.

Finally, in regard to the accelerating and decelerating lanes, those were liable to be used as lay-bys.

Mr Nigel Seymer (Editor, *International Road Safety and Traffic Review*) said that the Author had used the term "speed value" in the Paper. The term was not defined in the British Standard Glossary of Highway Engineering Terms, and the Author appeared to be using it in the same sense as the Americans used the term "design speed", which was defined in the Highway Capacity Manual as followed:—

> "A speed selected for purposes of design and correlation of those features of a highway, such as curvature, superelevation and sight distance, upon which the safe operation of vehicles is dependent. It is the highest continuous speed at which individual vehicles can travel with safety upon a highway when weather conditions are favourable, traffic density is low, and the design features of the highway are the governing conditions for safety".

Would the Author agree that that was the sense in which he had used the term "speed value"?

"Design speed" was related solely to minimum *stopping* sight distance. The values of that quantity for different speeds which were given in "A Policy on Geometric Design of Rural Highways" published in 1954 by the American Association of State Highway Officials (A.A.S.H.O.), were very similar to the values for minimum sight distance given by the Ministry of Transport (quoted by the Author) for dual-carriageway roads. It might be presumed that the values given by the Ministry for single-carriageway roads for various "speed values" were intended to allow for overtaking—i.e., they were values for "minimum *passing* sight distance" for various design speeds. The A.A.S.H.O. "Policy" gave separate values for minimum passing sight distance for two-lane and three-lane roads. They were much higher than the values given by the Ministry for single-carriageway roads (see Table 10).

The Author had referred to the need for lines to discourage overtaking at the approaches to junctions. Surely it was not necessary to discourage overtaking in both directions! What was needed was a type of marking which would indicate a restriction on overtaking in one direction only. The "barrier line" had been evolved in the U.S.A. to meet that

TABLE 10

Minimum passing sight distances for design (A.A.S.H.O. "Policy"): feet			Visibility distances laid down by Ministry of Transport: feet	
Design speed	Two-lane roads	Three-lane roads	Speed value	Single-carriage-way roads
30	800	—	30	250
40	1,300	—	40	450
50	1,700	1,200	50	650
60	2,000	1,400	60	900
70	2,300	1,600	70	1,200

red, and was now being used extensively in European countries. A Committee of xperts drawn from O.T.A. (World Touring and Automobile Association) and P.I.A.R.C. Permanent International Association of Road Congresses) was studying the question of ternational standardization of road markings, and would probably recommend the ternational adoption of "barrier lines".

Mr Seymer endorsed the Author's remarks regarding contrasting surface treatment. r Maule-ffinch had emphasized the importance of the mental impression the driver ceived from the layout as he approached an intersection. Extensive tests on that uestion had been carried out in the Netherlands; the results were to be described by Mr ap in a slide lecture to be given at the 1956 International Study Week in Traffic Engineer- g at Stresa.

Mr Seymer then showed a number of slides illustrating examples of junction design in rious countries. Fig. 27 showed three layouts for T or Y intersections given in the A.S.H.O. "Policy". Commenting on layout A, the "Policy" states:—

> "The undesirable aspect of this design is that left turning vehicles, in taking a natural course, cross a lane used by opposing traffic in a nearly head-on position at both the entrance and exit of the turning roadway, points a, b and c. At any but low speeds these crossings at such flat angles are hazardous . . .
>
> "The hazard of this general plan is less where the turning roadways are aligned as in layout B . . . The triangular island should be made as large as feasible, generally not less than 100 feet on a side and preferably upward of 200 feet. A stop sign should be placed at e."

Layout B was rather similar to the "modified Bennett" layout, except that the tri- gular island was so much larger. The "Policy" continued:—

> "Fig. C shows an acute-angle intersection, in which the upper (right-to-left) turning roadway is one-way. This may be undesirable on a 2-lane highway where traffic turning left from the through highway may be invited to enter the one-way turning roadway improperly. At minor intersections the one-way turning roadway is better eliminated and the plan simplified to that shown by the dashed line. Where the through highway is divided the possibility of the improper movement to the one-way connection is eliminated by the median".

Fig. 28 showed two layouts for T intersections of a kind more generally preferred in the .S.A., with a divisional island in the side road. Commenting on layout C, the Policy ated:—

> "The end of the island is generally located about 8 to 12 feet from the pavement edge of the through highway to fit the paths of left turning vehicles. This design is

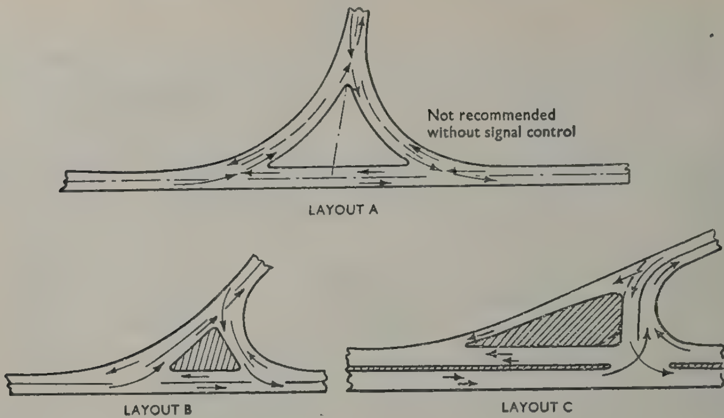


Fig. 27

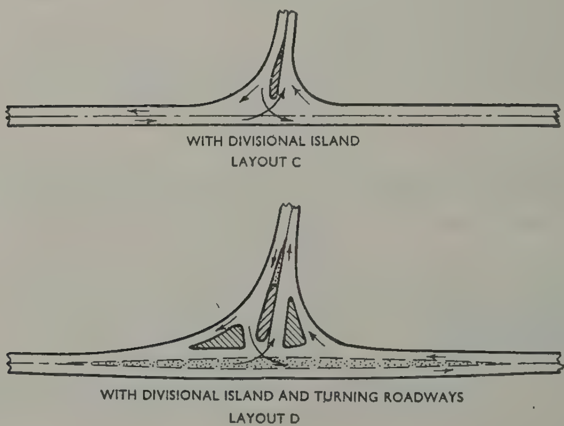


Fig. 28

adaptable to 2-lane highways over a wide range of volumes, particularly where spa is not available for turning roadways and where simplicitly is desired. For inte mediate to heavy volumes (relative to capacity of the highways), the through highwa preferably should be flared. . . .

"Fig. D shows an intersection with a divisional island and right turning roadways, desirable plan on important 2-lane highways carrying intermediate to heavy traff volumes, say peak-hour volumes upward of 500 vehicles on the through highway wit substantial turning movements. All of the movements through the intersection a accommodated on separate lanes."

Fig. 29 illustrated three different methods of flaring the main road at a T intersectio The A.A.S.H.O. Policy made the following comment on such flaring:—

"Where speeds are high and turning movements in sufficient number increa hazard, an additional area of surfacing or flaring may be provided for maneuverabili . . . *Flaring reduces hazard caused by turning vehicles and increases capacity.* Le

Fig. 32.—Recently reconstructed cross-roads at Laren

Fig. 36.—T-junction in Oklahoma (see Fig. 34)

Fig. 38.—Typical intersection in California with baffle island and jiggle bars

turns from the through highway are particularly hazardous because vehicles must slow down and perhaps stop before completing the turn. Flared intersections enable following through vehicles to maneuver around these slower vehicles. . . .

"Fig. D shows the added lane in the middle of the through highway. Here the additional lane is more likely to be used as intended than the additional lane shown in Fig. C. A driver turning left from the through highway naturally edges toward the center and through traffic is encouraged to pass on the right of the vehicle slowing down or stopping to turn left. There are similar advantages for vehicles turning left into the through highway."

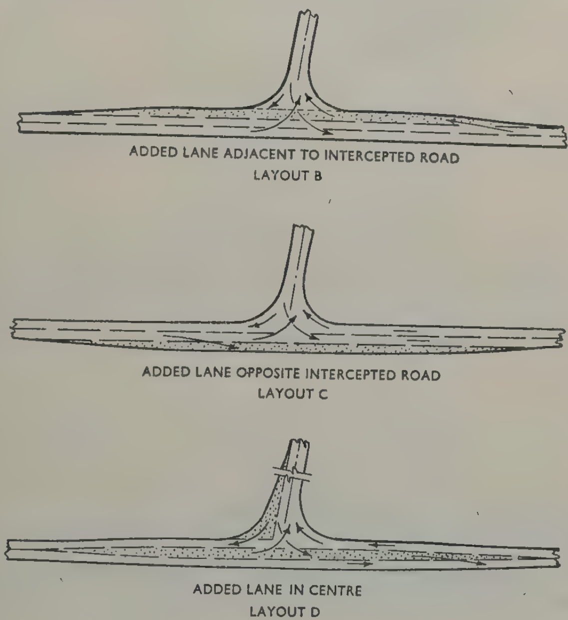


Fig. 29

Flaring of the main road at intersections was also favoured in Paris and in Belgium. In e latter country, three-lane highways were not divided into only two lanes at the ap-baches to an intersection, as in Britain; on the contrary, arrow markings were used, as own in Fig. 30, to encourage left-turning drivers to use the centre lane. Such an arrange-nt was surely preferable.

The arrow markings used in continental countries were bold, and elongated; one of the igns used in Germany was shown in Fig. 31.

n the Netherlands, a two-lane road was divided for a short distance into two 2-lane dways, each 6 or even 7 m wide, at the approaches to an important junction, and to add rt acceleration and deceleration lanes, especially for left-turning vehicles. An excellent mple of that type of treatment was the recently reconstructed cross-roads at Laren g. 32). (Roundabouts were not favoured in such cases in the Netherlands.)

n Switzerland, on the other hand, Mr Biermann, who had been responsible for the esign of a great many intersections, had in one case recommended the division of a m (three-lane) road into two 5-m ($1\frac{1}{2}$-lane) roadways at a major intersection, with hadowing lanes" for left-turning vehicles notched into the divisional islands (Fig. 33).

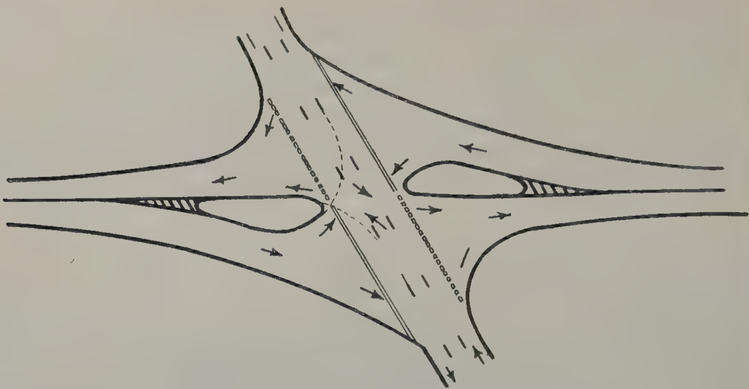


Fig. 30

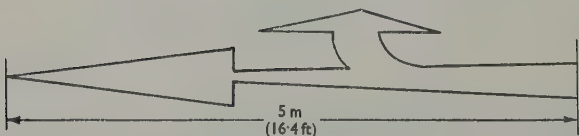


Fig. 31

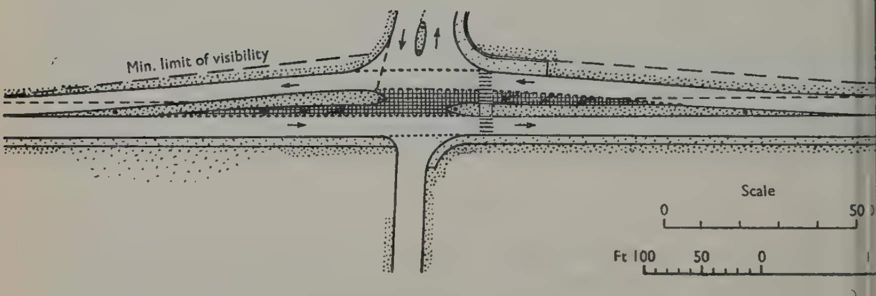


Fig. 33.—A typical Swiss major intersection

Fig. 34 showed the layout adopted at a T junction on a two-lane highway in Oklahoma. It had a left-turn "shadowing" lane, and 75-ft radii for both left-turn movements. The left turn into the main road was supposed to be made into an acceleration lane on the offside of the through traffic. The provision of such "median lanes" was illustrated in the A.A.S.H.O. Policy (Fig. 35), though in a recent text book[14] it had been stated that:—

> "There is some difference of opinion concerning the need for left-turn acceleration lanes because this movement is generally controlled by stop signs or signals at grade intersections".

[14] T. M. Matson, W. S. Smith, and F. W. Hurd, "Traffic Engineering". McGraw-Hill, 1955.

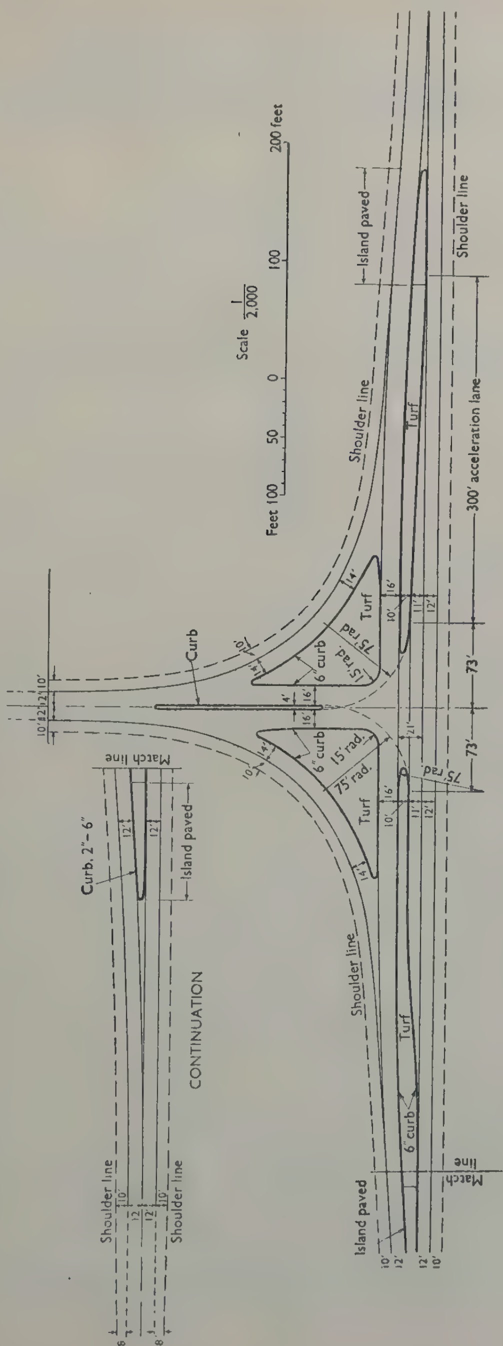
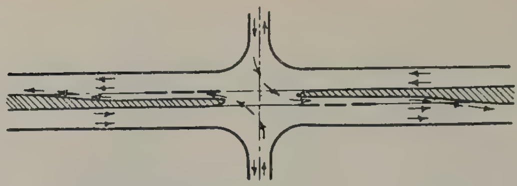
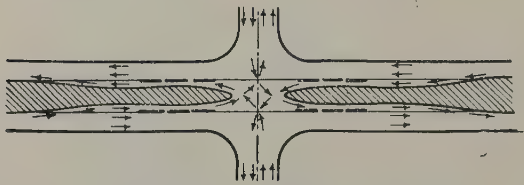


FIG. 34.—T-JUNCTION FOR TWO-LANE HIGHWAY IN OKLAHOMA



MEDIAN LANES FOR ENTRANCE TURNS



MEDIAN LANES FOR BOTH EXIT AND ENTRANCE TURNS

Fig. 35

The idea of merging from the offside was generally accepted in the U.S.A. However, , was not always practised by drivers, as shown by a photograph taken at the Oklahoma intersection referred to above (Fig. 36). The only way to force drivers turning left into main road to use a median acceleration lane was to construct a "baffle island" in the pos tion indicated by the dotted line in Fig. 37. Layout A in the same Figure showed a typic treatment for an important T intersection on a two-lane highway, with both flaring an channelization. Fig. 38 showed an intersection in California where such a "baff island" had been constructed; it consisted of an area of "jiggle bars" or ribs of concre projecting about 2 or 3 in. above the road surface.

In conclusion Mr Seymer drew attention to the Author's statement that, in his thr proposed layouts, "in each case the layout of the minor road is identical, and this considered to be an important factor, if a pattern of driver behaviour is to be established The Author had suggested that, in the present days of ever-increasing international trav by road, it was desirable to establish a world-wide "pattern of driver behaviour". Th would not be assisted by making drivers turning right into the main road cross over bo directions of through traffic and then merge with one of them from the near side. In mo countries, the idea of "merging from the offside" was accepted; and indeed "mergi from the offside" was frequently practised at many busy intersections in the Unit Kingdom (e.g., Royal Hospital Road/Chelsea Embankment). Mr Seymer hoped that wou be very seriously considered before that feature of the Author's proposed layouts w adopted.

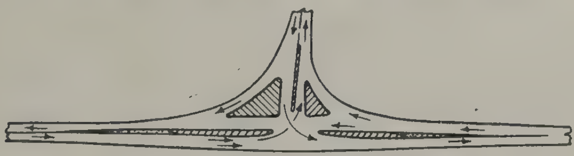
Mr R. S. Gallaher (Chief Traffic and Safety Assistant, County Surveyo Department, Bucks County Council) referred to the question of how the Author's desi could be applied to a particular site.

The Author based his design on vehicle speeds, which of course he was bound to c The junction was intended to be safe and to cater for moving vehicles. In the cou of the Paper the Author used various expressions such as "speed value of the roac "normal speed", and "average speed".

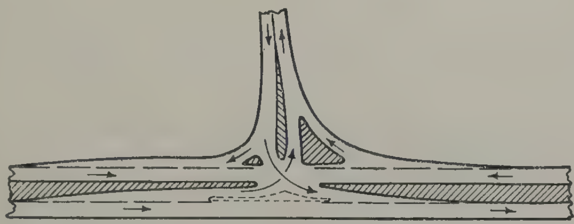
With regard to the "speed value" of the road, the only other time he had come acr that expression was in Ministry of Transport Memorandum No. 653, where the Minis made no attempt to explain what the expression meant. There was a suggestion in t

'aper that, in using "speed value", the Author found out what the vision distance was t a particular site and worked backward from the Ministry Table to determine what the peed value was or should be, but since the Author was designing his own vision distances nat did not seem very helpful.

With regard to normal speed, there was a suggestion that it should be taken as 70%



WITH DIVISIONAL ISLAND AND TURNING ROADWAYS
LAYOUT A



WITH MEDIAN LANES
LAYOUT B

FIG. 37

f the speed value. But since one did not know what speed value meant, one did not now what normal speed meant.

On p. 334 the Author stated that the designer must have as much regard to the abnormal s to the normal, but it seemed impossible for the designer to comply with that require-ent. The only way out of the difficulty was to eliminate the abnormal, and possibly e Author had something of that sort in mind. Mr Gallaher suggested that the only ay in which the abnormal could be eliminated by the highway engineer was to introduce andard speeds on all existing roads.

Mr Gallaher did not know to what extent the Author had used average speed; was it ggested that accidents were caused by vehicles which travelled at average speed? urely accidents were more likely to be caused by vehicles travelling at higher speeds.

Mr Gallaher, quoting from a Paper[15] which he had written on the subject of standard peeds in 1951, defined the standard speed of a road as "the highest uniform speed at hich it was intended eventually that a vehicle should be able to travel in safety along e whole length of that road".

How could a junction be designed unless it was decided beforehand what speed of pproaching vehicle was to be catered for? Apparently the highway engineer chose his vn speed. There was no consistency from one junction to the next, and there never ould be until standard speeds were officially adopted. Until then motorists certainly ere not likely to know at what speed they should be driving. It seemed that, when esigning, not only junctions but also bends, the placing of warning signs, the size of ttering on advance direction signs, etc., everything depended on the approach speed hich the highway engineer was supposed to be dealing with. Until that was decided

[15] R. S. Gallaher, "The case for standard speeds". *Surveyor*, vol. 110, p. 535 (25 Aug., 951).

and known, until not only the highway engineers but also the public knew what th speed was (which should be a certain standard speed for different roads of the sam class), it seemed impossible for the highway engineer to carry out his work effectively.

Mr G. A. Wood (Engineer, Ministry of Transport and Civil Aviation) said he wish to support Colonel ffolliott's plea for central refuges. The marking suggested by th Author for the vehicle waiting at the centre of a three-lane carriageway to turn right w perhaps ingenious, but in practice many drivers disobeyed the marking of white lines, an the physical warning and obstruction caused by a refuge was a far more comforting thi for the driver waiting in the centre of a road than any white line marking. The pa of refuges in the main road also showed up the presence of a junction at a considerab distance and prepared drivers for movements of traffic at the junction which were otherwi unexpected.

The suggestion that right-hand out-turning traffic should cross to the far side of t road and then go into an acceleration bay was perhaps not too sound. It put the driv of the vehicle in peril twice—once when he crossed the traffic from his left, and aga when he was merging into it in the acceleration bay. If the acceleration bay was the centre of the road, he had only to merge into the traffic without crossing it. T central refuges tended to give the driver some guidance as to what he should do. seemed natural for the driver turning right from the main road to proceed close up the central refuges and get into the gap between them, and, if there was traffic from t other direction, to wait there. There the driver was quite safe, whereas to wait in t middle of an unguarded junction required considerable nerve and, in darkness and ba visibility, could be very dangerous—there had been two fatal accidents in Hertfordshi to motor-cyclists in such circumstances. It should be remembered that some of t cheaper or older models had lights which went out when the cycle came to a standstill!!

*** **Mr J. J. Leeming** (County Surveyor, Dorset) wondered whether much of t discussion on speeds was not rather academic. With all due deference to the Americ Association of State Highway Officials, the accuracy of Table 6 was doubtful. T actual outward force on the back axle of the vehicle would be more than the "desi coefficient of friction" given in the Table. That was calculated from the lateral rati without allowing for the turning couple. The speeds given in Table 6 would ve decidedly be on the dangerous side on curves of the radii calculated, at the lower spee at any rate. Experiments by Mr Leeming with accelerometers had shown that anythi greater than 0·33 was risky.

In Fig. 4, it was not stated whether the intersection crossed by those vehicles w provided with a halt sign. If it was, it might be expected that the speed of traffic on t main road would be greater than if it were not, because of local knowledge of the existen of the sign.

Referring to "Carriageway marking" (see p. 343), Mr Leeming said he had expe mentally marked off two entrances on an important road with red reflecting studs, wi some apparent success.

Table 7, which gave figures for accidents at junctions provided with halt signs, was great interest. Some similar evidence was also available in Dorset. That had al given some reason to infer that accidents were more severe when the halt sign was presen At first sight, Table 7 did not seem to confirm that, though figures of non-injury acciden were not available in Dorset. It would be interesting to have the Author's commen on that.

With reference to the layouts given in Fig. 16, Plate 1, and Fig. 21, Plate 2, it w surely inadvisable to surround the striped areas with a continuous white line, since t Highway Code laid down that a continuous white line in the middle of the road should n be crossed as a general rule. Whilst the conditions were not similar, it nevertheless seem a bad principle to encourage crossing a continuous white line.

*** This and the following contribution were submitted in writing upon the closure the oral discussion.—SEC.

Mr J. L. Paisley (Senior Engineer, Ministry of Transport and Civil Aviation) bserved that it was the individual character of the problem at each junction that made lesign one of the most interesting and absorbing aspects of highway engineering. Rarely vere conditions of topography, traffic (both type and volume), and the limitations mposed by adjoining development precisely the same. It followed that there could be o stock solutions. Standard designs would only indicate the application of principles o a simplified presentation of the problem, generally level terrain, no development to omplicate the issue, and relative figures only for traffic. The design at each junction hould be "tailor made", by applying the principles to the particular problem.

The most difficult aspect of the problem was the traffic cut. The fly-over principle ould be developed in the horizontal and vertical planes to provide for unrestricted novement on the intersecting highways with no traffic cuts for vehicles using the inter-hange system. The solution was, however, expensive.

The roundabout avoided the direct cut by turning all the crossing movements into veaving actions. It was essential that all vehicles should negotiate the roundabout at pproximately the same speed, a point overlooked on occasion by those who were anxious o reduce the restriction which the roundabout inevitably imposed.

Signal control, rarely satisfactory in rural conditions, removed the traffic cut by llowing alternate movement of the several traffic streams and imposed even greater estrictions than the roundabout.

The Author had developed his principles from the study of accident data in that most ifficult case, the "T" junction where traffic conditions did not justify the more expensive olutions and where some traffic cuts had to be allowed. Mr Paisley, however, questioned he advisability of introducing one or more unnecessary traffic cuts for the vehicle turning ight out of the minor road, as was required by the introduction of the acceleration ane illustrated in Fig. 17, Plate 1, and Figs 21 and 24, Plate 2.

The Author had rightly emphasized in his introduction that a layout, to be satisfactory, ad to be as simple as possible, and that the method of negotiation should be patently bvious. Mr Paisley thought that the acceleration lane for right-turning traffic did not tisfy those requirements. Having crossed the opposing stream of traffic the natural novement for the right-turning vehicle was to weave into the new main road stream rom the offside. The weave was made difficult by the fact that the entering vehicle had o accelerate. That clearly raised consideration of traffic volumes. The weave (for ant of a better term) could only be accomplished if suitable gaps in the traffic stream ere available. When those conditions applied, the modified Bennett junction no doubt atisfied requirements for the two-lane road.

When traffic volumes on the main road had increased to a point where the merging novement could not safely be carried out from the Bennett layout the solution was, hought Mr Paisley, the provision of four lanes on the main road at the junction, physically ivided—a solution which would cater for the three-lane main road and, up to limited olumes, probably for the four-lane main road. The layout might be on the general nes of Fig. 24, Plate 2, but with better provision for the right-turning traffic to weave from the offside.

For higher traffic volumes on multi-lane roads grade separation with, in many cases, o interconnexion undoubtedly provided the only safe answer for the crossing of a minor oad.

As the Author had pointed out, intersections represented the greatest single hazard on oads and one where driver behaviour was a major element. There was undoubtedly a ase for further experiment with layout.

The Author, in reply, said that there was still a great deal to be learned about inter-ction design. Highway engineers hoped that they would soon be undertaking a very rge programme involving the improvement of existing main roads and the construction many miles of new road. He was not at all sure that currently accepted principles rovided the solution to the problems which they knew would arise at intersections on

those roads, and it was important that they should clear their minds of preconceived idea and approach the subject of intersection design in an experimental way if they were t learn what was the ideal layout to incorporate in any future new roads.

He agreed with the Chairman that they could not hope to apply any new design to ever junction in their respective counties—lack of funds would prevent that from happenin Nevertheless it was important that all junctions on new or improved main roads shoul function properly and with the least possible risk. It could not be said that that wa entirely true at present. Mr Keep had rightly drawn attention to the frequency of inte sections on main roads in Great Britain, and that was a feature which they must view wit grave apprehension as the volume of traffic increased. Probably in no other country wa there to be found an equally dense network of roads. The public had grown accustome to expect a direct route to their destination, and it was unlikely that Parliament woul sanction any powers for reducing the number of intersections on existing roads. Tha seemed an argument in favour of building new roads with limited access rather tha attempting the improvement of existing roads, and in the Author's view that argument wa strong. Similarly, Dr Smeed's comment that a central reservation might be provided on 30-ft road to assist the right-turning vehicle suggested to the Author that one migh establish a case for building dual carriageways in preference to a three-lane road because the number of intersections on it or the amount of turning traffic, even though the throug traffic volume alone might not be sufficient to warrant such provision.

Experience showed that intersections laid out in conformity with current Ministry Transport designs were the scene of many accidents and, on dual carriageways, were th cause of most of the accidents on those roads. There was evidently room for improveme in design. It did not necessarily follow that a particular design was at fault because it wa the scene of recurrent accidents; it might be overloaded. Nevertheless the Author wa convinced that there were many junctions—he could name half-a-dozen in his own count —which would not warrant the provision of roundabouts or fly-overs because of th comparatively small proportion of turning traffic, but which were accident black-spot It was at such sites that the Author thought that variation in layout should be tried.

He was grateful to Dr Smeed and to Mr Keep for emphasizing the underlying assumptio of the Paper that it was upon main roads carrying heavy volumes of traffic that inte sections became a problem. Clearly one would not apply the yardstick of 10% turnin traffic as a criterion for grade separation at an intersection on a country lane. It was n easy to lay down a basis upon which the needs of an intersection could be assessed, but th priority of any junction for the provision of grade separation would no doubt depend upo a combination of delays to traffic and accident rate. In the Author's view any inte section having more than 10% turning traffic on a road carrying at present more than 5,00 vehicles a day warranted consideration for grade separation in any plans for improveme In his experience any such intersection on a single level was an accident black-spot.

In applying the design to a particular intersection the Author agreed with Mr Duff comment that only those features need be incorporated which were necessary to meet th needs of the traffic, and with Mr Paisley's observation that the design at any junctio should be tailor made to meet local conditions; nevertheless, the basic pattern shou conform to a standardized layout. Mr Duff had commented, as had Mr Hadfield, on th unfortunate choice of junction at which the accidents were given in Table 8, but in t Author's experience it was very rare to find a junction at which traffic turned in and o equally right-handed and left-handed. At most sites there was a predominant flow which he had selected an example. He appreciated that the example quoted was n normal, but neither was any other. Mr Hadfield's suggested remedy for motor-cyc accidents sounded simple, but the Author frankly could think of no restriction short total prohibition which would have prevented the junction accidents they had recorde

The Author could not share Col ffolliott's enthusiasm for central refuges. Even built-up areas where speeds were comparatively low and street lighting was normal provided refuges were constantly being hit. In a rural area where speeds were higher, t results of such a collision would be correspondingly more severe. He shared Mr Wood

anxiety for the stationary vehicle in the middle of the road, but that did not seem to him to be a good reason for placing a permanent stationary object there—even if it were lit. Moreover, bulbs failed unexpectedly, and he would not like to contemplate an unlit obstruction in the middle of a fast road. In the Author's view the proper solution to a high accident rate at an intersection in the hours of darkness was the provision of adequate overhead lighting, but in rural areas that could not at present be achieved because the highway authority was not the lighting authority. In his view amending legislation was desirable, to allow the provision of lighting for traffic purposes where it seemed necessary.

Of the layout itself several speakers had criticized the provision of an acceleration lane on the far side of the main carriageway for the vehicle turning right-out of the minor road and Mr Hadfield, Mr Wood, and Mr Seymer in particular had suggested that merging should take place on the offside of the through traffic. He fully appreciated the force of the arguments advanced in favour of the alternative method, but he still remained to be convinced that it was more satisfactory. Such an amendment would clearly simplify and cheapen the design, but was it right to encourage drivers to merge on their blind side? In a private car one had reasonably good vision to the rear, but a van or lorry driver would be expected to weave across to the slow-moving side of the road without being able to see whether there were another vehicle behind him or not. On a dual carriageway the problem would be accentuated. Another practical difficulty was the provision of adequate turning radius to enable a large vehicle to enter from the offside. He did not think that drivers would be shy of using an acceleration lane on the far side of the road—he knew of cases where vehicles mounted the kerb on the far side of a two-lane road which suggested that they would have found themselves in the acceleration lane had it been provided. From the theoretical point of view it did seem that such accident figures as were available tended to suggest that it was safer to make that movement a square one rather than an oblique one. For example, a Road Research Laboratory investigation into accident rates at 232 rural junctions gave an average figure of 0·22 for square junctions and 0·35 for left-hand splay junctions in which vehicles executing the right-out and left-in movements were involved. It seemed reasonable to suppose that vehicles emerging from a left-hand splay did so by entering the offside of the following main road stream, and if that was so, the manoeuvre seemed to give a higher accident rate than one in which drivers crossed the main stream more nearly at right-angles to it. Mr Seymer had said that the idea of merging from the offside was generally accepted in the United States. It would be of great interest if accident figures were available for intersections designed on that principle. The Author believed that full-scale investigation of the opposing principles at a number of the sites where conditions of traffic speed and volume varied would be of the utmost value.

The Author could not agree with Mr Leeming that the question of speed was academic. The cruising speeds of popular makes of motor cars were undoubtedly higher than they were 20 years ago, and he thought that highway engineers would be wise to envisage even greater speeds in the future. He had used the term speed value in the sense used by the Ministry of Transport. He was in entire agreement with Mr Gallaher's definition of the standard speed of a road, but preferred the use of the term design speed, and he was convinced that the Ministry of Transport should designate appropriate design speeds for main roads to which the design of intersections, curvature, visibility, superelevation, and signs would conform. One of the present shortcomings of the highway system in Great Britain was in the Author's view a lack of uniformity in those features on any particular road, and insufficient differentiation between major and minor roads. That was particularly true of the size and layout of direction and warning signs. What was quite suitable for a minor road where speeds were comparatively low was inadequate for a main road where speeds were high.

The Author was particularly grateful to Mr Hanhart for his contribution on the question of road signs, since he was able to speak for a very large number of road users. It was clear that he (the Author) would not gain much support for the omission of route numbers from direction signs. He felt that a confirmatory sign of the type illustrated in Fig. 13 fulfilled a need. A sign of that kind erected experimentally in his own county had received

favourable comment, and, so far as he could ascertain, larger and clearer direction signs on main roads would be generally welcomed.

He was glad to note that there had been support for contrasting surface treatment. He was convinced that the clear definition of the through traffic lanes at an intersection was important. He realized that the use of kerbs to delineate the edge of the carriageway and to contain the traffic was open to objections and that there was much to recommend the provision of hardshoulders. Unfortunately the standard lane width in Great Britain had hitherto proved insufficient on two-way roads to dispense with kerbs, but it might be that with a more generous provision of width and with hardshoulders of adequate size and of contrasting colour, kerbs would no longer be necessary.

In reply to Mr Leeming, the intersection crossed in the example quoted in Fig. 4 was controlled by a "Halt" sign, but he did not think that traffic on busy main roads paid much attention to the nature of the control of side-road traffic. It was the inevitable result of frequent junctions on main roads that the through driver tended to ignore them; that was confirmed by recordings of speed at and between junctions, which showed no variation attributable to the junction, whatever the nature of the sign on the side road. Accidents at junctions provided with "Halt" signs were in the Author's experience undoubtedly more severe than at junctions not so controlled. He attributed that to the fact that visibility at those junctions was severely restricted, and if a vehicle emerged in the face of oncoming traffic the driver on the main road had no opportunity to take appropriate action, and a broadside rather than a sidelong collision usually resulted.

Correspondence will be published in a later number of the Proceedings.—SEC.

AIRPORT DIVISION MEETING

24 April, 1956

Professor A. J. S. Pippard, Vice-President, Chairman of the Division, in the Chair

The following Paper was presented for discussion and, on the motion of the Chairman, the thanks of the Division were accorded to the Author.

Airport Paper No. 30

THE INVESTIGATIONS, DESIGN, AND CONSTRUCTION OF PAYA LEBAR AIRPORT, SINGAPORE

by

*** John Jefferis Bryan, O.B.E., B.Sc., M.I.C.E.**

SYNOPSIS

The Paper deals with the investigations and survey of the site, giving physical properties of the soils encountered, the variation in depth of the water-table, and the methods used for determining the thickness of the runway and taxi-track pavements.

A suggested method of determining, by direct measurement, the ultimate bearing capacity of a soil under a sealed pavement at a known height above the water-table is described.

Reference is made to actual settlement and piezometric pressures observed in the field and these are compared with predicted settlements. Similarly, compaction attained in the field is outlined.

The strengths of concrete attained in the field as determined from 6-in.-dia. cores are given, as well as the rate at which ordinary cement concrete gains strength in Singapore compared with the corresponding rate in the British Isles.

The basis on which the drainage was designed and a description of how the work was actually executed in a country with 100 in. of rain per annum are given, together with information on quarrying, products of crushers obtained by varying the settings of jaws, the useful life of tires and tracks on heavy earth-moving machines, and a breakdown of the costs of operating plant as a percentage of the hourly cost of operating it together with the hourly cost of operation and total hours worked. The variation of hourly cost as the hours worked increased is shown.

The airfield lighting is described and reference is made to the major buildings and radio aids.

Introduction

It was realized in 1948 that a runway capable of carrying modern aircraft was required in Singapore. The Singapore Government sent the Author to Western Europe and to the United States of America to study the functional design of terminal buildings, and he was also enabled to study American methods of construction and approach to runway design. On his return to Singapore, the Author was instructed

* The Author was Chief Engineer, Paya Lebar Airport.

to investigate sites for a new airport, including the possibility of expanding the existing civil airport at Kallang. From his knowledge of the soil and local conditions and by studying the contour map of Singapore, he concluded that the site at Paya Lebar appeared the best and most suitable for development. Detailed investigations and surveys were made for the purpose of design. There were other good sites on the Island, but these could not be considered because, if developed, they would interfere with the operations from existing military airfields.

Description of site and layout of airport

The site (Fig. 1, Plate 1) is approximately 7 miles from the business centre of Singapore city. The approach road joins the city road system in such a way that either of two main road arteries can be used to proceed to the city and a new seaside road now under construction will increase the number to three. In addition, access to the mainland of Malaya and the military, air, and naval bases on Singapore Island can be made without having to journey through city thoroughfares. The first runway is on the foot of a hilly area, the building area is on more hills, which connect the first hilly area to other hills, on which the greater part of the future runway is to be made. Sufficient land for two runways was acquired because it was thought prudent to prevent the construction of permanent buildings on land which might be needed later.

The layout of the airport is indicated in Figs 1 and 2, Plate 1. It consists of two parallel runways with the building area between them. Should the second runway ever be constructed, one runway can be used for landing and the other for take-off. The runways are sited parallel to the Changi runway, and the distance between the produced centre-lines of the Changi runway and the runway just completed at Paya Lebar is about 4½ miles. Ultimately, the future maintenance area will be connected to the future parking area by a bridge over the approach road capable of carrying heavy aircraft. In addition to the runway and taxi-track lights, line and bar approach lights are provided at each end of the runway. The eastern runway, the one under discussion in this Paper, is capable of being quite easily extended to 10,000 ft. Fig. 3, Plate 1, shows the longitudinal sections of the runway and parallel taxi-track. The outfall sewer from one of the city sewerage works which runs through the site has influenced the siting of buildings and decided some of the levels of runway, taxi-tracks, and parking aprons. The runway is 8,000 ft long and 200 ft wide, the parallel taxi-track, sited 650 ft away from it, is 75 ft wide. The runway was designed to carry a 60,000-lb. equivalent single-wheel load. The level of the south end of the runway is 42 ft and of the north end 59 ft. The level of the coastal plain on which the business part of the city is built is about 15 ft. The design of the holding aprons at each end of the runway is such that an aircraft can proceed to the runway while other aircraft are warming up facing into wind on the holding apron.

Investigations and survey

From information shown on the contour map of Singapore Island, three longitudinal sections were plotted, one down a line considered to be approximately where the centre-line of the runway should be, one 500 ft to the east of it down the eastern edge of the strip, and one 700 ft to the west of it approximately down the centre-line of the parallel taxi-track. Tentative formation levels were shown on the sections. Bores were put down at 100-yd intervals, in the hilly areas to just below the tentative formation levels, and in the low-lying areas to 30 ft below tentative formation levels.

The depth of water-table was noted in each hole and disturbed samples of soil were taken at every 2 ft of depth and brought to the laboratory, where Atterberg tests and Proctor tests were carried out on them. These were carried out in cut areas at standard and modified compaction and C.B.Rs were taken on dry and soaked specimens. Where possible, undisturbed samples were taken at tentative formation level and C.B.R. tests were carried out on them. Undisturbed samples were also taken in the valleys and oedometer tests were made on some of them. The natural moisture content of all soils was noted. From the results of the Atterberg tests the soils were classified in accordance with the U.S. Civil Aeronautics Administration Classification, and the classification was noted on the longitudinal section together with the colour of the soil on each borehole. A soil mechanics laboratory (which was later developed into a concrete and bituminous materials testing laboratory as well) was set up, and local men were trained by the Author to carry out the necessary tests.

Fig. 4, Plate 1, shows a few examples of how moisture contents varied with depth and with the nature of the soil. There is no evidence that the moisture content of the soil decreases with depth even in the clays. Tables 1, 2, and 3, Plates 1 and 2, show natural C.B.R. results, Atterberg limits, moisture contents, etc., of undisturbed samples taken from excavation areas at tentative formation levels, the same properties of the soil taken from excavation areas at depths other than at formation levels, and the same properties taken on remoulded soils, respectively. From these it can be seen that none of the dry densities of the soils in situ were high. The moisture contents of the E6, E7, and E8 soils were very much above the optimum (see also Fig. 4). The results shown in these Tables indicated where to expect good soils in the excavation areas and surveys of these areas were later made in greater detail by boring to enable an assessment to be made of the quantity of good soil likely to be found on the site. Because of the high moisture content of E6 to E8 soils and the considerable depth of cutting below the water-table in the hill in the north-east corner of the site, it was deduced that it would be possible to excavate only a few feet depth at a time and that it would be necessary to wait for the soil to dry out from time to time as the depth of excavation increased. This deduction proved in practice to be only too true. By studying Tables 1, 2, and 3 (Plates 1 and 2) it can be seen that soils compacted at standard compaction lost between 70% and 90% of their C.B.R. values, and those compacted to modified compaction lost from 80% to 90% on soaking for 4 days. In spite of the somewhat low dry densities of the soils in the hills, building experience has shown that loads of 2 tons/sq. ft upwards can generally be imposed on them without undue settlement. Having obtained a large number of results, of which some are shown in Tables 1, 2, and 3, Plates 1 and 2, the problems which arose were: (*a*) to assess what compaction could be obtained in the field in a country with a rainfall such as Malaya's (see Fig. 5, Plate 1) with no definite seasons; and (*b*) what C.B.R. could be expected as a result of compaction. No information was available locally and a study was made of Reports on Soil Compaction Investigations Nos 1 and 2 of the Waterways Experimental Station, Vicksburg, U.S.A. (since the soils encountered at Paya Lebar were chiefly silty clays and clayey sands) to see if an assessment could be made. It was concluded that compaction between "standard" and "modified" would be attained and so a set of C.B.R. results were taken on soil compacted at "intermediate compaction" as shown in Table 3, Plate 2.

Using the information obtained, runway and taxi-track thicknesses were worked out by the U.S. Civil Aeronautics Administration method and by the C.B.R method.

The former method is based on the classification of the soil from its Atterberg limits, assuming good drainage and no frost. It was assumed that the more plastic soils encountered at formation level in cuttings would be excavated an additional depth of 18 in. and be backfilled with some of the better soils found in areas to be excavated. The E6 and E7 soils were definitely the best but the E8 soils did not appear to be so good as the E10 soils. The C.B.R. values at intermediate compaction were then studied and, bearing in mind the susceptibility of some of the better soils to small changes in moisture content, it was decided to adopt for design purposes a C.B.R. of 10. The compaction values attained in the field are given in Table 8, p. 393.

TABLE 4

	Thickness required: inches	
	C.A.A. method	C.B.R. method
Runways		
Flexible pavement		
Surface course	3	3
Base course (non-bituminous)	8	9
Sub-base	8	9
Total	19	21
Concrete pavement		
Concrete	9	13
Sub-base	8	—
Total	17	13
Taxi-tracks, parking aprons, and ends of runway		
Flexible pavement		
Surface course	3	3
Base course (non-bituminous)	10	10
Sub-base	10	10
Total	23	23
Concrete pavement		
Concrete	12	16
Sub-base	8	—
Total	20	16

TABLE 5.—DESIGN THICKNESSES

	Runway: inches	Taxi-tracks: inches
Sub-base	6	7
Dry-bound macadam base course	12	12
Bituminous macadam binder course	$2\frac{1}{2}$	$2\frac{1}{2}$
Densely graded bituminous concrete wearing course	$1\frac{1}{2}$	$1\frac{1}{2}$
	22	23

A comparison of the results obtained by using the two methods is given in Table 4. The modulus of subgrade reaction equivalent to a C.B.R. of 10 was taken as being 100.

The design adopted was for a flexible pavement with the thicknesses given in Table 5.

Concrete pavements for the maintenance apron were designed 16 in. thick in two slabs each 8 in. thick.

Evaluation of ultimate C.B.R. under a sealed pavement

Because of the difficulty of estimating the future moisture content and C.B.R. of the soil under the runway, the Author has for many years sought methods of estimating this. He has studied work now being carried out at the Road Research Laboratory and has seen experiments being carried out there to ascertain the ultimate moisture content of soils. He has learnt therefrom that this will depend on the P_f value of the soil, the height above the water-table, and the load on the soil. He believes that ultimate moisture content can now be calculated but the problem still remains as to how to assess what the ultimate C.B.R. value will be. If a piece of soil is placed in a tank on a layer of suitably graded sand some distance above an artificial water-table, and if the top of the tank is sealed to prevent moisture evaporating, the soil will suck up moisture from the water below and ultimately reach an equilibrium moisture content. The Author assumed that a thick piece of soil would take longer to reach equilibrium moisture content under such conditions than a thin piece. He thought that a sample of soil of the same diameter and half the height of a Proctor compaction mould would reach equilibrium in about 6 months and consequently had such a mould made which could be opened half-way up its height. Soil was either obtained in this mould (which could also be provided with a cutting edge) in situ from the subgrade of the runway or was compacted in it at standard or modified compaction. After the soil had been either obtained or compacted in the mould the two halves of the mould were separated and the soil therein was cut by a wire. The C.B.R. of one half of the soil was taken and the other half of the soil (still in the mould) was placed on top of damp sand in a tank at a known height above an artificial water-table, and the top of the tank was sealed with paraffin wax. After 3 months the soil was taken out and weighed and thereafter was taken out monthly and weighed until there was no change in weight for 3 successive months. When that occurred the C.B.R. was again taken. The results are shown together with the properties of the soil tested in Table 6, Plate 2. This contains the results of all the tests carried out. Some anomalies occur in that some of the soils gained both in moisture-content and in C.B.R. value. This is probably the result of laboratory errors. The results indicate that C.B.Rs varying between 10 and 15 can be expected ultimately under the runway pavement.

In addition to designing the thickness of the pavements, it was necessary to determine whether or not undue settlement would occur under high filling. This was of great importance for as much as 27 ft of filling was required in places. Oedometer tests on undisturbed samples were carried out and pressure/void-ratio curves were obtained for twenty-one different undisturbed samples of soil which well represented the types of soil encountered in the valleys which were to be filled in. From these curves the settlement in the valleys was calculated. When this was done it was considered that the soil above the water-table could be made to settle quickly by drainage and consequently a considerable amount of settlement could be effected before filling was deposited in the valleys. In those valleys thin clay layers and sandy

layers alternated and so it was considered that settlement would take place quickly and that by the time the pavement for the runway was constructed 80% of the settlement would have taken place under the runway and 50% under the taxi-track. Table 7 shows the settlements which were estimated.

TABLE 7.—SETTLEMENTS

Hole No.	A.18	A.22	A.51	A.54	A.57	H.18	H.21	H.39	H.45	H.51	H.57
Settlement: inches above water-table	1·0	3·4	1·3	1·1	1·4	4·3	2·2	0·6	1·8	2·6	3·5
Settlement: inches below water-table down to 30 ft	10·5	13·3	3·3	3·7	5·1	5·6	5·0	2·8	4·2	3·9	10·3

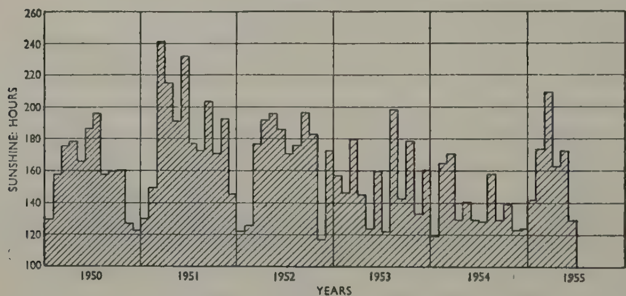


FIG. 7.—MONTHLY TOTALS OF SUNSHINE

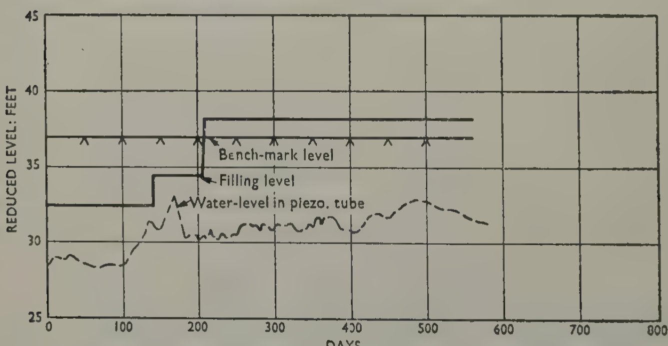


FIG. 8.—PIEZOMETRIC PRESSURE AND SETTLEMENT OF BENCHMARK NO. 5

Position: at chainage 67.00 approx. and 30 ft west of F line
Original water level: 27·83
Total settlement of benchmark: 0·11 ft
Original ground level: 32·49

Figs 8 to 12 show the piezometric pressures and settlements of benchmarks constructed on areas to be filled, which occurred as filling proceeded. The settlements

ctually observed varied from 1·32 in. to 1 ft 3 in., compared with those predicted hich varied from 3·4 in. to 1 ft 5 in. The two smallest settlements observed, amely, 1·32 and 1·56 in., were in areas for which no prediction had been made but hey are shown in order to indicate that comparatively little settlement took place ven under 12 ft of filling, although the dry density of the ground on which the fill was

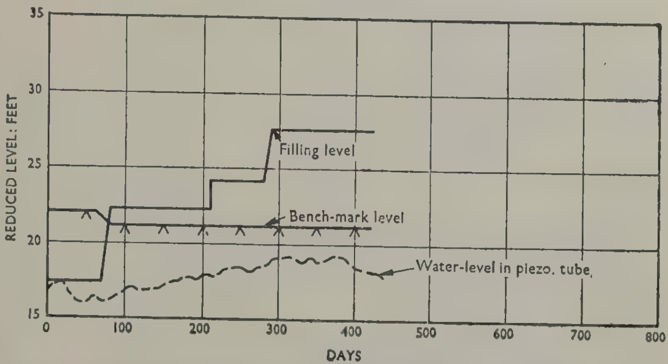


FIG. 9.—PIEZOMETRIC PRESSURE AND SETTLEMENT OF BENCHMARK NO. 6

Position: at chainage 58.40 and between H and I lines
Original water level: 16·49
Total settlement of benchmark: 1·06 ft
Original ground level: 17·38

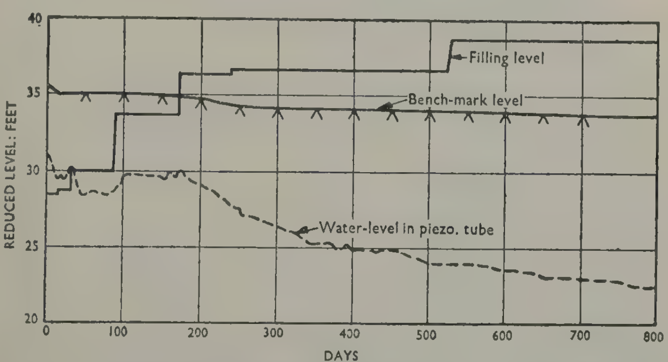


FIG. 10.—PIEZOMETRIC PRESSURE AND SETTLEMENT OF BENCHMARK NO. 1

Position: at chainage 17.00 and 15 ft west of F line
Original water level: 9·32
Total settlement of benchmark: 1·25 ft
Original ground level: 28·62

aced was less than 90 lb/cu.ft. The observed settlements shown in Figs 9 and 12 fer to the same areas as H.57 and H.21 in Table 7.

Settlement investigations for the design of the hangar foundations were carried t carefully because, in view of the large spans and the method of connecting the main of girders to the stanchions, differential settlements could not be allowed. Unrtunately, owing to lack of space, pressure/void-ratio curves for the settlement

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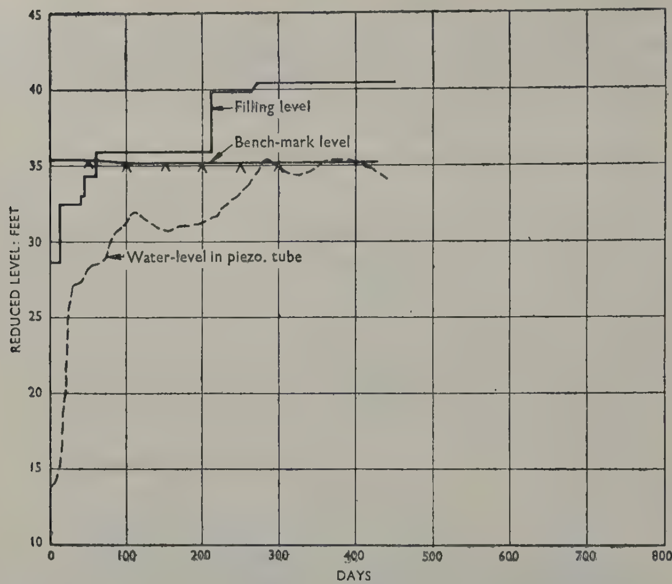


FIG. 11.—PIEZOMETRIC PRESSURE AND SETTLEMENT OF BENCHMARK No. 7

Position: at chainage 76.00 and 115 ft east of line A
Original water level: 21·62
Total settlement of benchmark: 0·14 ft
Original ground level: 28·63

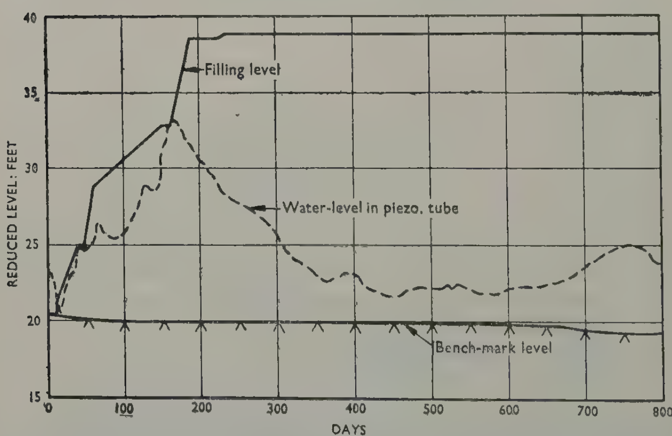


FIG. 12.—PIEZOMETRIC PRESSURE AND SETTLEMENT OF BENCHMARK No 2

Position: at chainage 21.00 and near F line
Original water level: 19·1
Total settlement of benchmark: 0·74 ft
Original ground level: 19·38

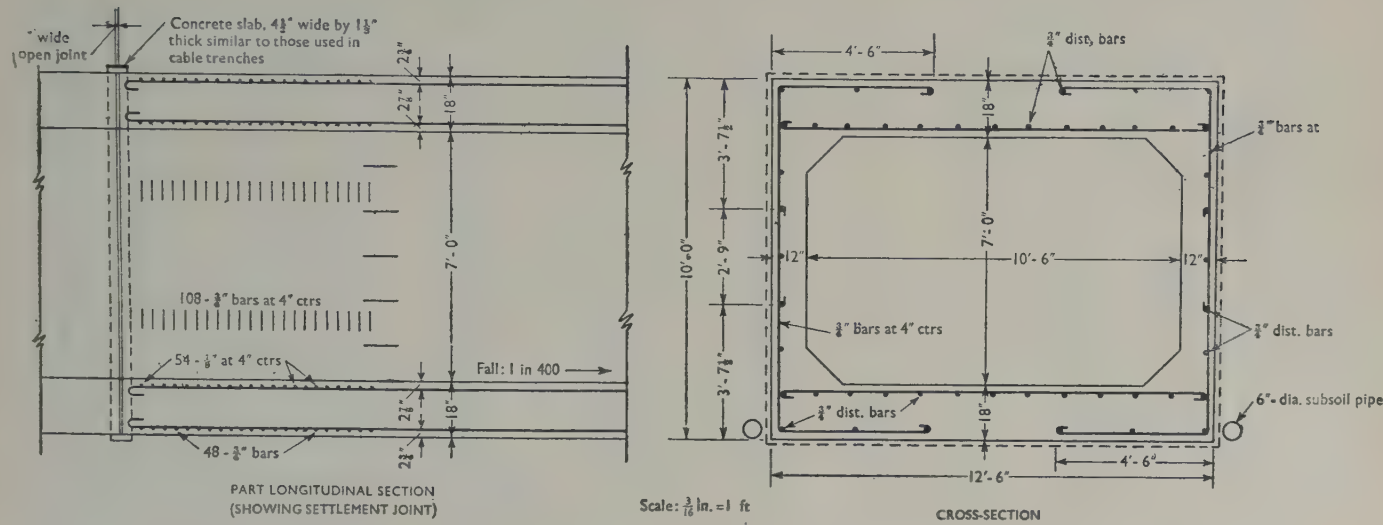


FIG. 13.—DETAILS OF CULVERT NO. 2 BETWEEN MANHOLE NO. 9 AND OUTFALL

investigations of the hangar foundations and under high fills cannot be incorporate in the Paper.

Drainage

The first essential in the construction of earthwork in Malaya with unpredictab rains is to ensure that good drainage is provided throughout the progress of the wor Two valleys cross the site of the airfield approximately at right angles to the runwa and it was consequently necessary to design and construct two culverts, one of whi (No. 2) is shown in Fig. 2, Plate 1. The first of these was constructed as a bo culvert 6 ft × 5 ft at the top end and a 6 ft × 6 ft at the lower end. The second w constructed 6 ft × 6 ft at the top end and 10 ft 6 in. × 7 ft at the lower end. Th construction of these two culverts was the first work to be commenced on the projec A bridge, 60 ft long, was also constructed where the drainage channel crossed a existing road at just above high-tide level. Box culverts were constructed in 20- lengths with a 1-in. joint between each length in case differential settlement occurre A cross-section of the lower end of culvert No. 2 is shown in Fig. 13. The draina was designed to deal with a rainfall intensity of 6 in./hour for 20 min. Coefficien of run-off adopted were:—

Paved areas	0·90
Graded grass areas	0·30
Ungraded natural hilly areas . . .	0·25

This gave an average run-off of 2½ in/hour taken over the area of the airfield itself.

The cross-section of the runway and main taxi-track is shown in Fig. 14, Plate The drain 100 ft east of and parallel to the runway is buried and consists of reinforc concrete spun special-strength pipes. All open drains were constructed of preca slabs (see Fig. 25, facing p. 400). An unorthodox section, adopted for one of t larger open drains, consisting entirely of flat slabs, is shown in Fig. 15, Plate 2. the contract for making the flat slabs, minimum breaking strengths in bending a densities were both specified. Special-class pipe culverts were constructed whe transverse taxi-tracks crossed over the main open drain. No concrete haunches foundations were provided to these although some of them were constructed on much as 20 ft of filling.

The concrete in the box culverts was required to have a minimum compressi strength of 2,850 lb/sq. in. at 28 days, which figure was attained in the field. It w vibrated by immersion-type vibrators. All backfilling was compacted by compresse air rammers.

Many miles of subsoil drains were laid to take away excess water in the ground. deep cut-off intercepting drain was cut at the eastern edge of the strip but it could n be kept clear during construction. It was realized that when grading is complet and the cut-off drain is working properly the subsoil pipes will have very little wo to do, but they were considered necessary to drain the site while work proceeded.

All culverts were designed to take a 60,000-lb. equivalent wheel load; the effect this at various depths was calculated by the Boussinesq formula and is shown Fig. 16a.

Water-drops were incorporated in all concrete drains to keep the water veloc down to 10 ft/sec. To prevent erosion of embankments, intercepting drains w constructed at the top and water reached the main drains by means of sumps a 6-in. pipes placed at 75-ft intervals, as shown in Fig. 15. Strip turfing was provi to the sides of drains above the concrete lining but no other turfing was provided

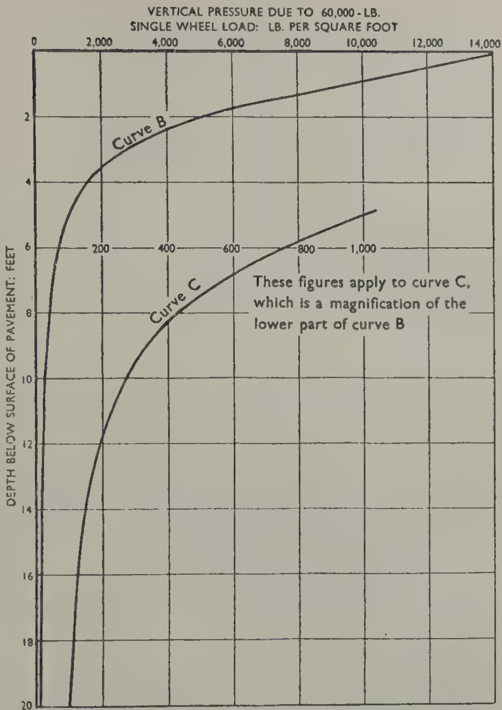


FIG. 16a.—PRESSURES DUE TO 60,000-LB. EQUIVALENT WHEEL LOAD (FROM BOUSSINESQ FORMULA)

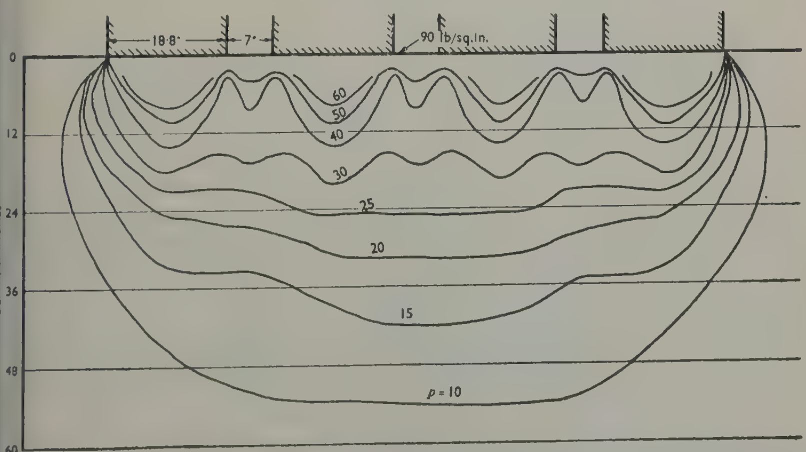


FIG. 16b.—DISTRIBUTION OF VERTICAL STRESS p (LB/SQ. IN.) BENEATH "ROLLAPACTOR"
(One wheel load: 25,000 lb. Tire pressure: 90 lb/sq. in.)

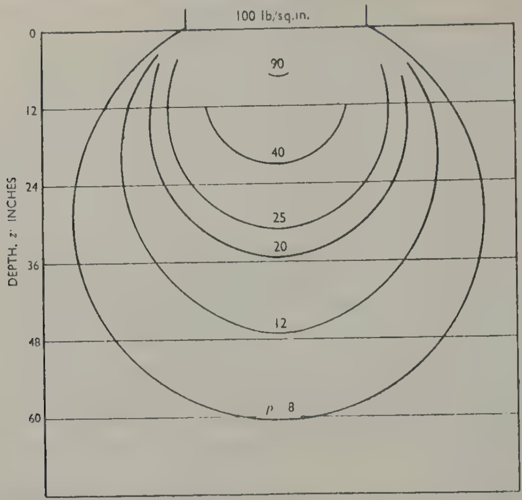


FIG. 16c.—DISTRIBUTION OF VERTICAL STRESS p (LB/SQ. IN.) BENEATH SINGLE WHEEL LOAD OF 60,000 LB.
(Tire pressure: 100 lb/sq. in.)

the airfield. On other areas, top soil was spread 2 in. thick and grass grew of its ow accord.

CONCRETE PARKING APRONS FOR AIRCRAFT

Concrete aprons were constructed in the maintenance area and northern an southern holding points. These were constructed in two layers, each 8 in. thick, th bottom layer to a minimum strength of 3,000 lb/sq. in., in bays 25 ft × 20 ft, an the top layer to a minimum strength of 4,000 lb/sq. in. at 28 days, in bays 25 ft 20 ft, with a dummy joint in the middle which made apparent bays of 12 ft 6 in. 20 ft. Dowels of 1 in. dia. at 12-in. centres were provided all round the edg of each bay. The joints in the top slabs were, so far as possible, situated over th centre of the bottom slabs. Longitudinal expansion joints were provided 120 apart and transverse ones at intervals of 240 ft. No dowels were provided in th longitudinal expansion joints but the edges of the slabs were thickened to 12 in Bituminous paper was laid on the ground before the bottom slabs were laid. Th surface of the bottom slabs was painted with bitumen before the top slabs were lai Bays were laid alternately. The concrete was vibrated by immersion vibrators an finished by external vibrators. Portable batch weighers of 2,800 lb. capacity we used for proportioning the aggregate and cement. Cores were cut in the concrete t ensure that minimum strength was attained. It is very important that cores shou be prepared very carefully for testing and it was found that cores should not be take until the concrete has been laid for at least 21 days. 560 lb. of cement per cubic yar were specified for the top and 445 lb. for the bottom slabs.

General remarks on concrete

All high-quality concrete was vibrated with immersion-type vibrators. In add tion to taking cores, concrete cubes were prepared at the time of mixing in the usu

manner. It was found that ordinary concrete gained strength in Malaya nearly as quickly as rapid-hardening cement in Great Britain (see Fig. 17). This is very important information particularly in estimating the strength at 28 days from a sample

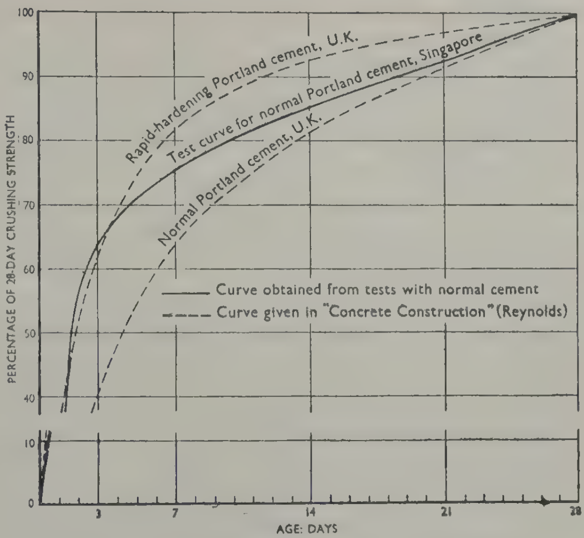


FIG. 17.—AGE STRENGTHENING OF CONCRETE

tested at 7 days. If the British curve were used a strength at 28 days much above the actual figure would be deduced. From the tests on concrete it was found that:—

1·72%	of results gave strengths of more than	20% below minimum specified
1·9%	,, ,, ,, ,, ,,	10%–20% below minimum specified
3·6%	,, ,, ,, ,, ,,	0%–10% below minimum specified
9·1%	,, ,, ,, ,, ,,	0%–10% above minimum specified
13·0%	,, ,, ,, ,, ,,	10%–20% above minimum specified
70·6%	,, ,, ,, ,, ,,	20% above minimum specified.

EARTHWORK AND CLEARING

The greater part of the area was covered with coconut trees, of which it was necessary to remove approximately 30,000 complete with roots. The trees were felled with a crawler tractor equipped with a special tree-pusher. They were pulled to either the eastern or western side of the airfield and dumped. They would not burn when newly felled but as work proceeded the local people came and cut them up and took them away for burning after they had dried out. The top-soil in places was between 12 and 18 in. deep. This is a rare occurrence in Malaya.

A list of major equipment purchased is given in Appendix I.

It was decided to use electrically operated self-propelled scrapers of approximately 6 cu. yd capacity because of the long hauls and their high speeds. Rubber-tired dozers were used for push loading because they could continue to push at a speed sufficient to enable second gear to be reached by the self-propelled scrapers before the rubber-tired dozer was left behind. Earthwork started in August 1952.

In view of the high and frequent unpredictable rainfall in Singapore, with no definite dry and wet seasons, as can be seen from Fig. 5, Plate 1, it was necessary to work in such a way as to keep the working areas as dry as possible. Excavation was started on the hill at the north end of the runway and filling at top end of the valley near culvert No. 1, which crosses the runway centre-line at chainage 16.00. A good track was made to connect the excavation and filling areas to enable the speed of the machines to be kept as high as possible. Good slopes were kept both on the excavation and filling areas and temporary drains were constructed and maintained to direct the water away from them as much as possible. Filling was compacted by sheepsfoot and rubber-tired rollers as soon as possible after the filling was deposited. Work was stopped during rain and not restarted before the water had run off. It was only because of these precautions, particularly the compacting of the filling quickly after it had been laid, that the comparatively high output was achieved. In the valleys the poorer soils were placed first and when the filling reached to within 4 ft of finished earth level, the better soils were then deposited. The maximum depth of cutting in the northern hill was 54 ft. The excavation was carried out in strips about 100 ft wide. As soon as the water-table, which followed the slopes of the hill at a depth of about 12 ft, was reached it was necessary to leave the strip concerned to enable it to dry out and move to the next strip up the hillside. During the excavation of this hill it was found that some of the better soils, because of their sandy nature, became very difficult to work after rain, whereas the soils containing more clay could quickly be worked after rain because they shed most of the rain which fell on them. Once laid and compacted, however, so long as traffic over them was not permitted during rain, the more sandy soils retained their stability. The worst and most difficult soils to work were the silty-fine-sands. In this hill many varieties of soil occurred, varying with depth as well as location on plan, from kaolins to coarse sand containing a small quantity of silt and clay.

In spite of the high and intermittent rainfall in Singapore the quantity of earthwork carried out per month was higher than people in the United Kingdom might expect. This is because of precautions taken as described above, as well as the fact that when the sun shines it is very hot and the top inch or two of ground which was wetted by the rain soon dries out. Although the rainfall during some months of 1954 was relatively low, the quantity of earthwork carried out was low because the rain was prolonged instead of intense and hours of bright sunshine were comparatively rare (see Figs 5, Plate 1, and Fig. 7). Monthly records of earthwork completed are shown in Fig. 6, Plate 1. From the end of April 1954 earthwork figures began to drop. This was due to wear and tear on machines, longer hauls, alternate wet and dry months, less hours of sunshine, and the fact that the surface of the airfield was taking shape, which resulted in very much flatter excavation and filling areas.

It was found that when the ground was too wet for rubber-tired machines to work it was also too wet for satisfactory compaction and consequently no time was lost due to the alleged inferiority of tractive power of the rubber-tired machine as compared with the crawler. It was also found that if the rubber-tired machines worked down-hill the ruts formed by the wheels acted as drains. Crawler tractors were found to churn up earth when wet so much that if they travelled frequently over the same track they became bogged down on that track. Tracks used for a prolonged period by rubber-tired equipment became so dense and smooth that they could be used immediately after rain.

Compaction and densities attained in the field

Compaction was accomplished by a 100,000-lb. roller on four pneumatic-tired wheels, a sheepsfoot roller weighing 40,000 lb. on 5-ft-dia. drums, and a wobbly-wheel roller weighing about 12 tons on nine pneumatic-tired wheels. The heavy rollers were pulled by an Allis Chalmers H.D.20 crawler tractor. The lighter roller was used for the initial compaction. In view of the climate, compaction at optimum moisture content by design could not be achieved although it was found that freshly excavated soil, compacted soon after being deposited had a moisture content near the optimum. As the rollers passed over the soil when the sun was shining they squeezed out a certain amount of moisture which quickly evaporated. The counting of the number of passes to attain the desired density was not practical and compaction was continued until the desired density was attained. It was always attained in the fillings but it was found difficult to attain in certain cutting areas. The drying-out of the soil in hot spells increased the densities considerably.

Densities in the field were found by the pycnometer method. The densities of the various soils similar to those used under the runway in the top 3 ft were obtained at modified compaction and samples were kept in glass jars, for in most cases it was possible, with practice, to identify the soil by visual inspection and touch. Where densities were taken in the field the samples so obtained were compared with similar samples in the laboratory, of which the modified compaction density was already known; this enabled the relative densities of the field sample and the laboratory sample to be assessed. The aim was to get compaction equal to 95% of modified compaction under runways and taxi-tracks in the top 2 ft of the subgrade. Of 1,000 field density tests carried out 15% failed to reach 95% of modified compaction. Most of these were in cutting areas.

Table 8

Type of soil. C.A.A. No.	Density obtained expressed as % of that at modified compaction			Actual density: lb/cu. ft		
	Minimum	Maximum	Average	Minimum	Maximum	Average
E.7	93	102	96	112	124	117
E.8	94	102	96	106	123	113
E.10	94	100	97	112	123	117
E.11	94	101	97	105	121	110
E.12	93	106	96	96	106	99

Table 8 is a summary of compaction results obtained in filled areas. The averages given are the average of all results.

When the desired densities could not be attained in cuttings the 100,000-lb. roller was put over the area concerned and since the water-table was not less than 5 ft deep the area was passed if the roller made no appreciable settlement or marks. From Figs 16b and c it can be seen that the pressure so exerted on the soil by the

roller was $2\frac{1}{2}$ times as great as that of an equivalent single-wheel load of 60,000 lb acting on the soil through a pavement 22 in. thick.

Quarrying operations and construction of runway

It was decided to proceed with the construction of the runway pavement as soon as possible so that pavement construction could proceed simultaneously with the earthwork. Very extensive building construction was proceeding in Singapore and the demands on the available sources of stone on Singapore Island were very extensive. Moreover, to bring stone from quarries on Singapore Island meant that lorries would have to travel at least 15 miles over narrow and congested roads. Visits were made to Pulau Ubin* and it was decided to investigate a site which appeared promising for opening up a new quarry. A report by a geologist, written about 1949 indicated that there were 8,000,000 cu. yd of granite on the site. Boreholes found rock generally at 20 ft and less where it was not visible on the surface and very large boulders were visible on the surface, so it was decided to open a new quarry, install crushing machinery, and construct an unloading depot on the Serangoon River at a site about 1 mile from the north end of the runway. It was also decided to install the bituminous mixing plant at the unloading depot. The crushers were installed near the quarry on Pulau Ubin because the stone barges were loaded by belt conveyor and unloaded by a clamshell crane. Such a crane would not have been able to handle block metal.

Deep overburden was at first removed by sluicing from monitors supplied by pumping sea-water at a delivered pressure of 52 lb/sq. in. This pressure was a little too low for the soil encountered as overburden. Once quarrying had commenced "jetting" away the overburden was stopped, for it made the quarry floor too wet and muddy.

There was at first some disappointment, because most of the rock was found to be boulders, some of which were as large as 60 ft long by 55 ft deep by 25 ft wide weathered in situ. However, outcrops were developed and eventually a daily output of 400 to 450 tons of stone was quarried and crushed.

Tungsten-carbide cross-type taper bits were used with 1-in. hexagonal-shank jackhammers. Holes were drilled to depths ranging to 18 ft, using bits $1\frac{3}{8}$ in.–$1\frac{3}{4}$ in. dia. The average life of a $1\frac{5}{8}$-in. bit was found to be 260 ft of drilling, which produced 200 tons of rock ready for spalling.

An average of ten jackhammers were used daily to produce 430 tons of stone for primary and secondary blasting combined. The total capacity of the air compressors used was 1,200 cu. ft/min at 100 lb/sq. in.

Table 9.—Materials required per ton of stone

Gelignite	0·19 lb. for primary blasting
Blasting gelatine	0·05 lb. for secondary blasting
Detonators	0·9 rounds
Safety fuse	4·0 ft
Fuel oil	0·11 gal for crushers
	0·07 ,, for dumpers ($\frac{1}{2}$-mile lead)
	0·11 ,, for excavators
	0·2 ,, for air compressors

* Pulau=island; ubin=granite.

Stone was broken by spallers into blocks, the maximum size of which was 20 in. × 14 in. It was then loaded by $\frac{3}{8}$-cu.-yd excavators into 3-cu.-yd dumpers, which transported it and dumped it straight into the crushers. After it was crushed it was transported direct to the barges by belt conveyor.

In order to obtain the sizes of stone required it was necessary to vary the opening in the jaws of both the 30-in. × 16-in. crushers and the 36-in. × 9-in. granulator. For a crusher-jaw-setting of 3 in. the following sizes were obtained:—

% smaller than $\frac{3}{4}$ in.	% $\frac{3}{4}$ in. to $1\frac{1}{2}$ in.	% $1\frac{1}{2}$ in. to 4 in.	% rejects
12	11	49	28

When the rejects were passed through the granulator the products expressed as a percentage of total stone crushed by the crushers and granulator were as shown in Table 10. The figures show percentages passing through screens with circular holes and will vary with: (*a*) the wear on the screens; and (*b*) the wear on the jaws.

TABLE 10

Setting of granulator jaws: inches	Smaller than $\frac{1}{2}$ in.: %	$\frac{1}{2}$ in. to $\frac{3}{4}$ in. %	$\frac{3}{4}$ in. to 1 in. %	1 in. to $1\frac{1}{2}$ in. %	$1\frac{1}{2}$ in. to 4 in. %
3	1	2	—	—	25
$2\frac{1}{2}$	3	3	—	—	22
1	9	8	—	11	—
$\frac{3}{4}$	9	9	10	—	—

The life of the crusher jaws was found to vary considerably with the size of stone crushed. Primary jaws, crushing 4 in. down, had a life of 17,000 tons for each fixed jaw and 15,000 tons for each swing jaw if the jaws were turned bottom up when the bottoms had worn appreciably. Granulating jaws when set to produce $1\frac{1}{2}$-in. stone had a life of 1,300 tons for fixed jaws and 1,000 tons for moving jaws. When worn too much the granulator jaws were built up by welding and had the same life again. When worn the second time they were built up again and run until completely worn out. When the granulator jaws were set to produce $\frac{3}{4}$-in. stone a set of fixed jaws lasted for only 500 tons and moving jaws 900 tons before it became necessary to rebuild them.

While the quarry was being developed and crushers were being installed the unloading jetties and bituminous mixing plant were constructed and erected. The area developed was found to be a little too small, for it was necessary to stockpile there 2,000 tons of bitumen at a time.

The chimney supplied with the mixing plant for the extraction of dust was only 25 ft high and it was necessary to increase it to 50 ft to enable operators to work in the batching cabin. It was still not quite high enough but 60 ft would have been satisfactory.

The materials handled at the unloading jetties included all the stone crushed at the quarry, quarry waste for the sub-base, and bitumen. Materials required for

bituminous macadam and bituminous concrete were stockpiled around the plant, but quarry waste and stone required for the base course were unloaded directly into tippers so far as possible. If, however, tippers were delayed these materials were stockpiled so as not to delay the turn-round of the barges. When barges arrived late tippers were loaded from stockpiles. The quarry waste and stone required for the base course were unloaded with a crane fitted with a $\frac{3}{4}$-cu.-yd shallow clamshell provided with teeth. This crane unloaded an average of 800 tons of material in a 24-hour day. The stone required for the bituminous pavement and dust were unloaded by a crane using a $\frac{3}{8}$-cu.-yd shallow clamshell fitted with teeth at the rate of 350 tons in an 18-hour day. The hours per day stated include the time the machines were stopped for servicing. Up to the time of opening the airport these two cranes had unloaded 300,000 tons of materials.

It was decided to construct the runway with the sub-base 6 in. thick, the base course 12 in., the bituminous carpet $2\frac{1}{2}$ in. of binder course in bituminous macadam, and the wearing course $1\frac{1}{2}$ in. thick of densely graded bituminous concrete. Bitumen 80–100 penetration was used. The taxi-tracks, aprons, and ends of runway were constructed to the same specification, except that the sub-base was 1 in. thicker. For the sub-base 90,000 tons of quarry waste were used on the runway and that part of the taxi-tracks completed for the opening of the airport. This quarry waste, of which the specification is given in Appendix II, was obtained from the floor of a quarry used to produce boulders for the Johore Causeway.[1] It was purchased and delivered to the airfield at half the cost of crusher-run stone. Quarry waste was laid

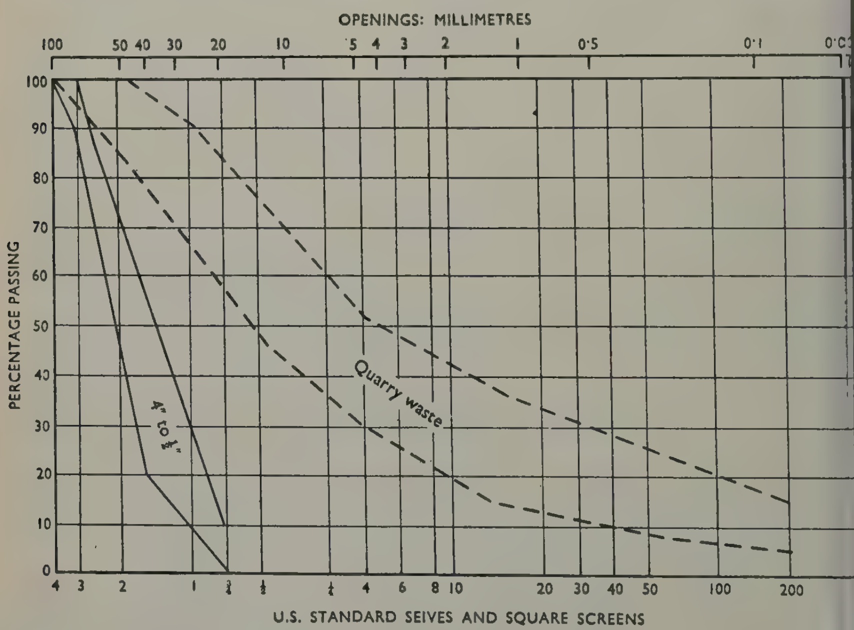


FIG. 18.—GRADING SPECIFICATION FOR QUARRY WASTE AND 4-IN. TO ½-IN. BASE COURSE

[1] D. Paterson, "Johore Causeway." Min. Proc. Instn Civ. Engrs, vol. 220 (1924–25), p. 250.

by self-propelled scrapers and graded by graders and compacted with wobbly-wheel and smooth-wheel rollers.

The base course was constructed in four 3-in. layers of 4-in. crusher-run stone from which all stone minus ½ in. had been extracted. It was blinded with ½-in.-to-dust screenings and rolled to a density of 150 lb/cu. ft. No water or gravel was added to blind the stone. The base course was laid by Jaeger spreader (Fig. 26, facing p. 400). Rollers weighing 12 tons effected the required compaction; they towed drag-brooms to brush in the dust screenings. One roller compacted, on an average, 7 tons of base course per hour in 4-in. crusher-run stone. The grading of the stone used is shown in Fig. 18. A large quantity of dust (screenings) was obtained from heaps which had been lying in quarries for years. Had it not been for these heaps of dust it would have been necessary to install crushing rolls to produce the large quantities of dust required for blinding the base course and for the bituminous pavements.

The costs and quantities of materials required to produce 1 sq. yd of runway pavement are as follows:—

The cost of producing, transporting, and laying 1 ton of stone was as follows:—	Including depreciation: dollars*	Excluding depreciation: dollars
Drilling, blasting, and spalling	3·64	3·42
Transporting to crusher	0·60	0·29
Crushing and loading into barges	0·56	0·30
Maintenance of plant, housing workmen, removing over-burden, and overheads	1·50	1·30
Total cost of quarrying, crushing, and loading into barges	6·30	5·31
Cost of crushed stone loaded into barges	6·30	5·31
Sea transport	1·10	0·64
Unloading	0·40	0·19
Tippers transporting to runway	0·63	0·41
Spreading with Jaeger spreader and rolling	1·07	0·67
Total per ton, spread	9·50	7·22
The cost of spreading quarry waste by self-propelled scrapers, grading with grader, and rolling (per ton)	1·05	0·64
Blinding with dust and rolling excluding cost of dust (per ton)	3·70	3·55
Cost of dust delivered on runway (per ton)	3·53	3·10
	7·23	6·65
Cost of bituminous macadam (per ton)		
At the mixer	28·90	24·87
Transporting	0·76	0·43
Laying and rolling	0·29	0·20
Total:	29·95	25·50

* One dollar (Malayan) is equivalent to 2*s* 4*d* sterling at the time of writing.

Cost of dense bituminous concrete (per ton)		
At the mixer	30·61	26·98
Transporting	0·76	0·43
Laying and rolling	0·29	0·20
Total	31·66	27·61

Cost of payment per square yard		
Quarry waste in sub-base 6 in. thick	0·30 ton at a cost of	$1·43*
4-in.—½-in. stone in base course, 12 in. thick	0·55 ,,	$6·24
½-in.-to-dust screenings to blind the base course	0·14 ,,	
Bituminous binder course	0·15 ,,	$4·49
Bituminous wearing course	0·10 ,,	$3·17
Total cost per square yard		$15·33

The transporting, laying, and compacting of stone proceeded throughout the 24 hours daily. Only seven tippers, each of 5 tons capacity, were used to transport the sub-base and base course and two tippers of similar capacity to transport the bituminous binder and wearing courses.

Before the final compositions of the bituminous macadam and bituminous concrete were decided upon, extensive laboratory tests were carried out in order to obtain the most stable results. In order to achieve this object the following tests were carried out:—

> *Stability*, by the Marshall Apparatus, which should be between 1,500 and 2,000 lb. with the load applied at the rate of 2 in/min.
>
> *Flow*, or deformation in inches which occurred immediately before the sample failed. This should not be greater than 0·2 in.
>
> *Voids in the mix*, which should be between 2·5% and 3·5%.
>
> *Density of mix*, obtained by carrying out a test similar to the Proctor compaction test and determining the bitumen content required to give maximum density.

As a result of tests carried out, the gradings shown in Figs 19 and 20 were adopted. These Figures show also the gradings in use in the United States and on runways in Great Britain. In the mixture used on the runway 4·89% of bitumen, expressed as a percentage weight of the total mix, was used in the binder course and 6·25% in the wearing course. Filler used amounted to 4·6% in the binder course and 9·66% in the wearing course, expressed as a percentage of the weight of the aggregate and filler combined. The filler material consisted of cyclone dust and cement. The average density obtained from cores cut after the pavement was laid was 145 lb/cu. ft in the binder course and 143 lb/cu. ft in the wearing course.

The fuel used in the bitumen-mixing plant was high-speed Diesel oil and 0·31 gal/ton were used by the engine and 3·10 gal/ton for heating bitumen and stone. The plant was electrically operated, electric power being generated on the site by a 75-kW Diesel-electric generator. A 10-h.p. generating plant was used to heat up the bitumen before starting the plant.

The bituminous courses were laid by a Barber-Greene spreader and finisher. The maximum quantity laid per week was 2,000 tons of binder course and 1,500 tons of wearing course. Within a short time of laying the bituminous course a 3-ton roller

* Includes depreciation on plant. Rate of depreciation is given in Appendix I.

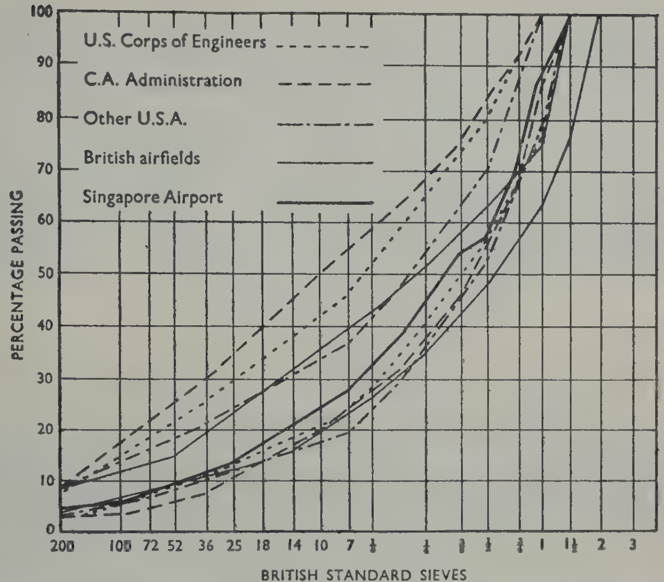


FIG. 19.—GRADING CURVE FOR ASPHALT MIX. BINDER COURSE—BITUMINOUS MACADAM

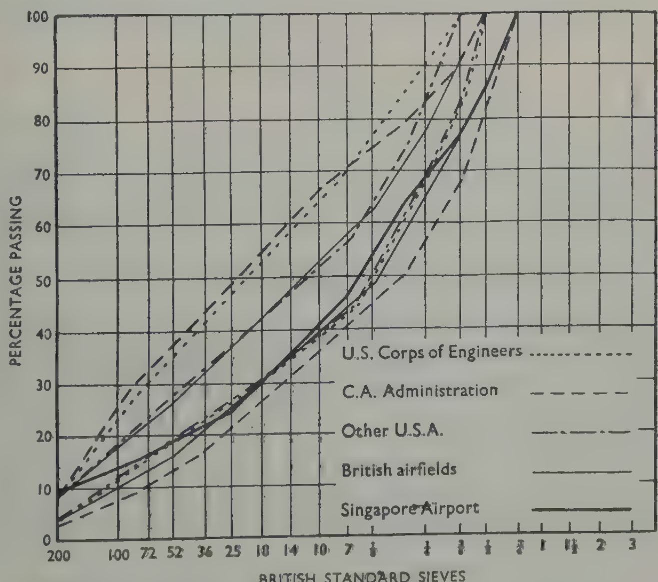


FIG. 20.—GRADING CURVE FOR ASPHALT MIX. WEARING COURSE—DENSELY GRADED BITUMINOUS CONCRETE

was run over it and later, when it was not too hot to be able to keep one's hand comfortably on it, a 12-ton tandem roller was used for compacting it.

The construction of the pavement of the runway, 8,000 ft long by 200 ft wide, was completed within 15 months. At first, considerable set-backs in the production of stone in the quarry were experienced but, in spite of this, 90% of the runway pavement was constructed between July, 1954, and May, 1955.

Marking runway and taxi-tracks

The centre-line marked on the runway was 3 ft wide, consisting of Crystallex in the centre foot bordered by Constructex 1 ft wide on each side.

Aprons and refuelling system

The maintenance area, as already stated, was constructed in concrete, but the terminal apron was constructed in macadam. Two hydrant refuelling bays were provided in the maintenance apron and ten in the first stage of the terminal apron. On the actual area, where aircraft are refuelled on the terminal apron, 8 in. of concrete was provided over an area 75 ft × 97 ft on top of 7 in. of sub-base and 8 in. of base course. An undercarriage parking system was adopted and the nose-wheel track, undercarriage parking positions, and refuelling points are shown in relation to the concrete standing in Fig. 21. The concrete surface was provided because it was

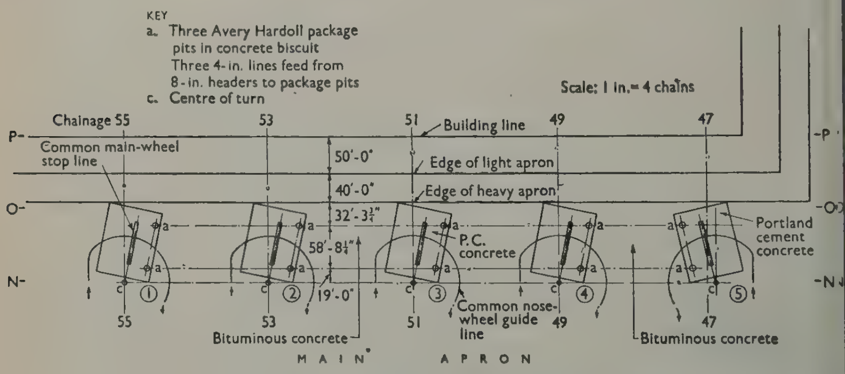


FIG. 21.—SITE PLAN OF AIRCRAFT FUELLING POINTS

considered that spillage from jets would damage a bituminous surface. Fig. 21 shows the spacing of five of the refuelling points. This spacing is suitable for parking jet aircraft in positions Nos 1 and 5 at any time and in positions Nos 2, 3, and 4 provided that when the aircraft goes in to park the position to the south is vacant.

The fuelling system, which was designed and constructed by the Shell Co. of Singapore Ltd, is of the hydrant type and, together with the cost of underground tanks, pumps, etc., cost £75,000. It is designed to deliver, in the first instance, 350,000 gal of aviation fuel each month and will permit the delivery of any three of the four grades available to aircraft, parked at any point on the parking aprons up to distances of 1,900 ft from the pumps in the tank farm. Up to fifteen four-engined aircraft will be able to park at the fuelling points and could, if necessary, be fuelled simultaneously from ninety ground-connexions.

Fig. 25.—Monsoon drain

(a)

(b)

Fig. 26.—Two views of Jaeger Spreader laying 4-in. to ½-in. base course

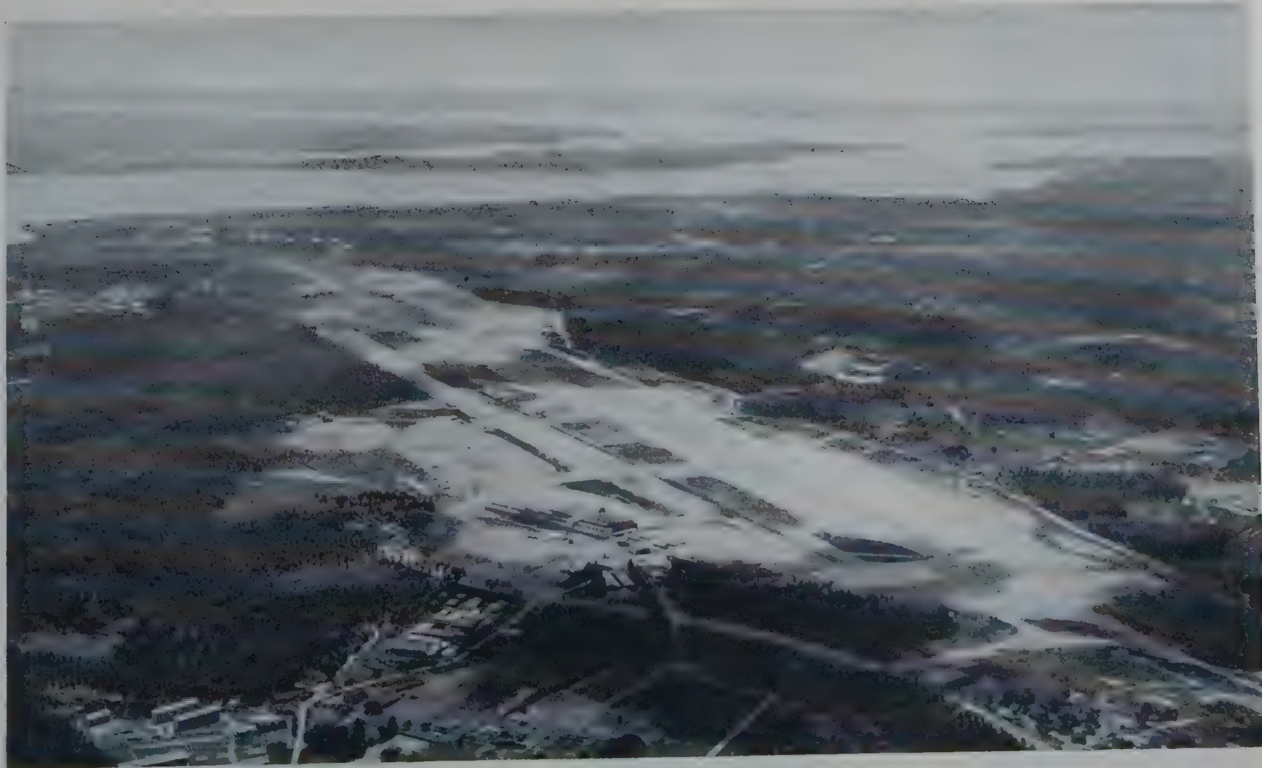


Fig. 27.—Aerial view of site on 16 July, 1955

Six steel tanks each having a capacity of 21,800 gal were completely buried in the round. Each tank was grit-blasted internally with metal grit and painted with iree coats of catalysed Epikate 1001 formulated enamel which gave a perfectly nooth and petroleum-resistant surface. Pump suctions in the tanks are mounted n floats to ensure that fuel is taken only from near the surface. The pumps are ounted in pairs; the aviation gasolene pumps will deliver 400 gal/min and the irbine fuel pumps 800 gal/min per pump. Pumps are press-button started and iould the delivery of one of the pair fall below the prescribed figure the second imp starts up automatically to assist it.

The delivery mains are 8 in. dia., concrete lined. The hydrants and pits consist of shut-off valve and a ground-coupling unit contained in a cast-iron pit, embedded a concrete apron. When not in use the pit is covered with a heavy cast-iron cover ipable of withstanding a load of 40 tons. The ground-coupling unit incorporates a pring-loaded self-sealing valve within a cast phosphor-bronze body provided with ie International standard three-point bayonet flange.

To prevent confusion at night and to avoid the possibility of delivering the wrong ade of fuel, the ground units are fitted for selector couplings, so that unless the rrect combination between the ground unit and dispenser intake coupling is used, upling cannot take place.

The dispenser unit, through which the fuel passes from the pit to the aircraft, is mpact and mobile and comprises an intake hose with self-sealing coupling to fit into ie valve in the pit, a nylon paper micro-filter which removes all foreign matter down 5 microns in size, a metering unit, a control valve which stops the fuel flow if the essure exceeds a predetermined maximum which, if exceeded, would damage rcraft fuel tanks, and a dispensing hose and nozzle mounted on a reel.

Airfield lighting

A modified "Calvert" line-and-bar approach-lighting system is provided at each id of the runway. It comprises a centre-line of lights for a distance of 3,000 ft om the threshold on the extended centre-line of the runway and two crossbars, one ted 1,000 ft and the other 2,000 ft from the threshold. Provision of cable has been ade for a third bar sited 3,000 ft from the end of the runway should it later be found be desirable. The lights on the centre-line are spaced 200 ft apart and on the cross-rs 9 ft apart. At each position in the pattern of lights, one high-intensity uni-rectional white light and one low-intensity omni-directional red light are provided. ie high-intensity lights are of 60,000 c.p. maximum. The intensity can be varied om the control tower in five pre-selected degrees. The high-intensity system will used during heavy rain and the low-intensity system in good weather. On both stems, additional distance indication is given by grouping three lights on the centre-ne at 3,000 ft distance, two lights at 2,000 ft, and one light only at 1,000 ft from the reshold. This lighting system operates at 24V, 200W.

Elevated frangible runway lights are provided at approximately 200-ft centres ong each side of the runway. They are of medium to high intensity (6,000 c.p.) id are provided with brilliancy control which can be operated from the control wer. They are beamed in elevation at 4° above the horizontal and pointed in at 2° wards the centre of the runway. On landing the pilot sees the first 6,000 ft of light white and the last 2,000 ft as amber.

The threshold lights are of flush type set 5 ft in from the end of the runway and aced at 12 ft-6-in. centres. They are bi-directional and fitted with 360° green filters.

These lights are on separate circuits from the runway lights since they are not controlled for brilliancy.

Half the runway lights are controlled from the northern and the other half from the southern end to ensure that if one sub-station failed alternate lights would still be visible. For a similar reason the approach lights are on two circuits but each circuit is from the same sub-station. Each of these three systems of lights is "series" connected to ensure that all lights in either of the systems operate at the same brilliancy. Lights are connected to the cables through 1-to-1 isolating transformers.

Taxi-track lights are blue, of the elevated low-intensity type spaced at 150 to 160 ft centres. The lights are divided into sections which are operated from the control tower, and by lighting certain sections and omitting others, the taxying route for an aircraft to follow can easily be seen from the cockpit of an aircraft.

In addition to the lighting described above, a locator beacon, an identity beacon, obstruction lights, apron floodlights, and illuminated sock-type wind-direction indicators are provided.

Fifty-three miles of 660V cables were used for the airfield lighting. The whole of the lighting installation is by finger-tip control in the control tower. These controls are grouped together on a special airfield lighting control desk which incorporates a mimic diagrammatic layout of the airfield and its lighting system. Back-indication, operated by current transformers in the outlying circuits, provides the control officer with positive indication that the circuits which he has operated are working.

Automatic standby Diesel generating sets were installed to take over all essential loads in the event of failure of the mains supply. They start, run up to speed, and take over full load within $4\frac{1}{2}$ sec of a mains failure.

Electrical energy is taken in bulk from the Singapore City Electricity Authority at 6,600V. Three sub-stations were constructed on the airfield:—

(1) The main incoming sub-station with a high-tension capacity of 950kVA of which 600kVA is converted to low tension to feed the hangar area, interim terminal building, various ancillary buildings, and half the runway, taxiway, and approach lights; and 355kVA is passed on at high tension to:—

   (a) the radio receiving station (5kVA)
   (b) the sub-stations referred to in (2) and (3) below;

(2) the sub-station at the north end with a capacity of 50kVA to feed half the runway, taxiway, and approach lights; and

(3) the sub-station feeding the fuel farm with a capacity of 300kVA.

The maximum demand on opening the airport was 750kVA and the ultimate expected load is 1,500kVA.

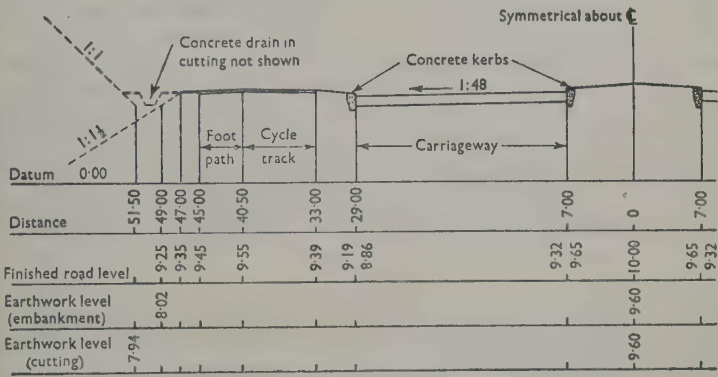
In addition to the control of airfield lighting already referred to, it is possible to alarm the fire-station in the event of a crash, and switch off all power supplies to the fuel pumps from the desk in the control tower. Airfield-lighting transformers, saturable core reactors, and relay-contactor gear are housed in air-conditioned control centres, one at the north end and one at the south end of the airfield.

In a central electrical control room all alarms from generators, sewage pumps, location beacons, etc., are received. A special indicator shows in mimic form the attitude of all LT and HT switch gear in the sub-stations. Fire alarms over various parts of the airfield in addition to operating local alarms indicate in the fire-station the source of the alarm and the time at which the alarm was made. All clocks are actuated from a battery-driven master impulse clock in the electrical control room.

Construction of roads

From Fig. 1, Plate 1, it can be seen that it was necessary to construct a road deviation around the north end of the runway and a new approach road to the airport. The deviation was constructed about 2½ miles long and 22 ft wide. It consisted of 9 in. of dry-bound macadam covered with 2½ in. of water-bound macadam, which was seal-coated with 80–100 penetration bitumen. It presented no problems.

The construction of the approach was a much more difficult matter for it crossed a belt of peat of very recent origin and an old river bed for a distance of about 700 yd. Filling was transported by self-propelled scrapers and dumped, working from the middle outwards. The new filling displaced the peat and went down for depths ranging to 30 ft. The peat rose to heights of 12 ft and the ground cracked and heaved for distances up to 200 ft from the centre-line of the road, lifting wooden houses in the process. On one section which did not settle materially, whereas it was thought from the results of the boring that heavy settlement should have occurred, an extra 4 ft of filling was added to the filling in an attempt to make it settle. This



Scale: 1 in. = 20 ft

Fig. 22.—Typical half-cross-section on approach road

caused settlements of as much as 6 ft and displaced the bad ground. It was thought best to get rid of the bad ground if possible during construction and thus avoid further prolonged settlement. If prolonged settlement had been acceptable filling would have proceeded from the outside of the embankment, working in towards the centre, and vertical sand drains would have been provided. This method would have required less filling. The approach road was constructed as shown in Fig. 22.

Costs of running machines and maintenance thereof

Table 11, Plate 2, shows the hours worked, costs of running per hour, and percentage of hourly costs of various components which made up these costs, of some of the more important machines used on the project. It is thought that by careful study these figures would assist in assessing the economic life of the various machines. It is interesting to study how the costs of depreciation plus repairs varies with time.

Although they are not given in sufficient detail to be of much value to contractors for the purpose of competitive tendering, it is thought that they may be of use to

those who have to prepare original estimates for schemes, such as consultants and members of various works services. By studying the costs a comparison can be made of the costs of moving earth by crawler-tractor and towed scraper *versus* the cost of self-propelled scraper. The speed of the latter on medium hauls can be taken as three times and, on long hauls, five times, the speed of the former. Speeds up to 35 m.p.h were obtained with self-propelled scrapers returning empty to the excavation areas.

A set of tires on the self-propelled scrapers lasted, on an average, 2,600 hours compared with 1,900 hours for a set of tracks on a Class B crawler-tractor. The tracks and rollers of the latter wore out comparatively quickly because:

(*a*) they were of cast iron; and

(*b*) the tractors were used for clearing top-soil which was generally wet and contained a considerable quantity of sand in adhesive soil.

With the rubber-tired tractors it was possible and economical to have the tires relugged. During 8,000 hours working of a machine it was necessary to relug all the original tires once and to purchase two new tires (per machine).

All machines were serviced at the end of each shift. Machines and engines were not taken down for complete overhaul at the end of predetermined periods but were watched carefully by mechanical engineers and were completely overhauled only when indications appeared that it was time to do so or when a part broke which necessitated a lengthy wait of a machine in the workshop. One spare engine was purchased to enable a faulty engine to be replaced quickly in the earth-moving machines, tippers, and lorries and the machine was sent out to work again with the minimum delay. The engines driving the crushing and Blackmix plants have each run 4,000 hours and there are as yet no signs of a major overhaul being required.

Buildings

While the construction of the airfield was progressing the following buildings were designed and constructed:—

(1) Two hangars, each 150 ft × 150 ft × 35 ft clear height, together with offices, workshops and stores; and the workshops, offices, stores, and foundations for a third hangar 300 ft × 150 ft span.

(2) An area air-traffic-control centre.

(3) A fire-station.

(4) Twenty-six ancillary buildings such as a meteorological station, police station, bonded stores, minor workshops, offices, and canteens.

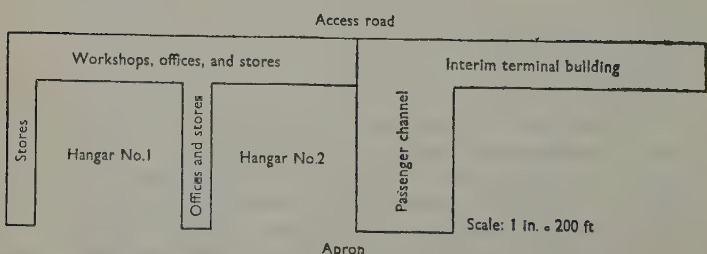


Fig. 23.—Interim terminal building and hangars

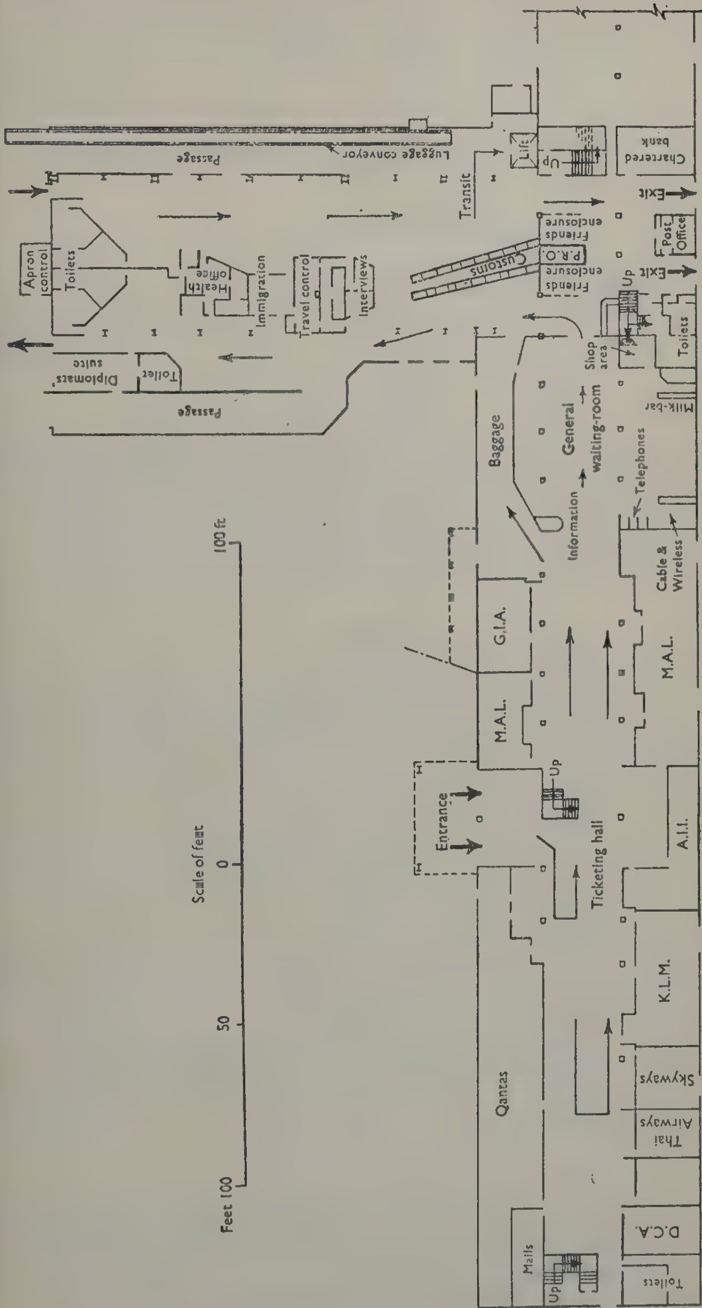


FIG. 24.—PASSENGER FLOW THROUGH INTERMINAL BUILDING

The hangars which have already been built were moved from the present civil airport at Kallang and the 300 ft × 150 ft hangar still in use at Kallang, for which the workshops, etc., and foundation have already been built at Paya Lebar, will be moved and re-erected there in due course. The layout of the hangars and their workshops and stores is shown in Fig. 23. The workshop, store, and office space of the 300 ft × 150 ft hangar have already been built at Paya Lebar to enable them to be used as an interim terminal building. Fig. 24 shows the passenger flow through the building.

Fire-station

The fire-station was constructed 126 ft × 45 ft × two storeys high with a hose-drying tower 69 ft high. A small workshop and store are on the ground floor, where there is also accommodation for eight vehicles, including fire engines, ambulances, and rescue vehicles. Dormitories, kitchens, and lecture room on the first floor.

Radio aids

A control centre to control all aircraft movements in the Singapore area, a locator beacon at the north end and one at the south end, a V.H.F. transmitting station, a V.H.F. receiving station, and a V.H.F. direction-finding station were provided in addition to the usual control-tower equipment and teleprinters. The equipment was provided and installed by the Department of Telecommunications in buildings constructed by the airport construction organization.

General

The earthwork and the construction of the bituminous pavements together with their base courses and sub-base, laying of long lengths of cable, and wiring of airfield and approach lighting were carried out directly by the Chief Engineer's staff. All concrete, building work, and internal electric wiring were carried out on contract. Earthwork was started in mid-August 1952 and by the end of June 1955 3,800,000 cu. yd had been moved and compacted.

By the time the work was started the airfield formation and the two main box culverts had been designed. The remainder of the designing was carried out as work proceeded. The hangars, workshops, interim terminal building, and fire-station were planned and designed entirely by engineers.

The senior staff consisted of the Chief Engineer and a pupil civil engineer working on investigations, planning, and design up to January 1952, when they were joined by a civil engineer. In August 1952 a plant supervisor and a mechanical superintendent joined the staff. The staff was later increased by one more civil engineer in October 1952, a pupil civil engineer in October 1953, another civil engineer, an electrical engineer in November 1953, and a structural engineer in July 1954. Until June 1954 the Chief Engineer and the electrical engineer were the only two chartered engineers engaged on the project.

Acknowledgement

The Author's thanks for permission to present the Paper are due to the Chief Secretary, Singapore, and for the information concerning the refuelling arrangements to Mr R. S. Jack, A.M.I.Mech.E., of the Shell Company of Singapore Ltd. Thanks for a great part of the knowledge which enabled the Author to plan and carry out the

work are due to members of the Civil Aeronautics Administration in the U.S.A., Ministry of Civil Aviation, London, and members of the staff of the Building Research Station and Road Research Laboratory, Great Britain. Mr E. Adamson was responsible for the information given in Fig. 16a concerning the rate of gain in strength of concrete.

APPENDIX I

LIST OF MAJOR PLANT PURCHASED AND RATE AT WHICH IT WAS DEPRECIATED

	Cost each: dollars *	Rate at which depreciated per hour: dollars
1. *Earth-moving*		
Eight self-propelled electrically controlled scrapers (186 b.h.p., 16 cu. yd)	97,500	10.00
Five rubber-tired tractors and dozers (186 b.h.p.)	80,700	9.00
One Super Class 1 crawler-tractor (175 b.h.p.)	80,200	8.00
Three Class 2 crawler-tractors, dozers, power-control units, and winches (78 b.h.p.)	55,600	5.00
Two heavy graders (100 b.h.p., weight 23,600 lb.)	49,000	5.00
One towed scraper (8 to 11 cu. yd)	24,200	3.00
2. *Compacting equipment*		
One pneumatic roller on four wheels (weight 100,000 lb. when filled with saturated sand)	47,100	5.00
One sheepsfoot roller (40,000 lb.)	18,800	2.00
One wobbly-wheel roller on nine wheels (weight when loaded 12 tons)	Second-hand	
One vibrating roller, towed	4,000	0.50
Two air-compressors (each 110 cu. ft/min) with four vibrators	Second-hand	
Three air-compressors (each 65 cu. ft/min) with six rammers and vibrators	Second-hand	
3. *Materials handling equipment*		
One Diesel-driven crane on crawlers with two ¾-cu.-yd clamshells and pile-driving equipment	85,200	10.00
Five excavators (⅜ cu. yd capacity) with three draglines, one backacter, one Toredo trencher, three face shovels, and two clamshells	35,700	4.00
Two Chaseside shovels	17,500	2.00
4. *Transportation equipment*		
Five 5-ton lorries		
Nine 5-ton tippers		
Petrol driven	9,500	1.50
Diesel ,,	12,700	2.10
Eight dumpers (each 3 cu. yd capacity)	12,800	1.30
One dumper (4 cu. yd capacity)	25,300	3.00
Three jeeps	Second-hand	
One Land Rover		
		per day
One tug (150 b.h.p.) — Written off in 10 years	164,000	60.00
Five barges (each 150 tons) — Written off in 10 years	82,000	30.00
Two barges (each 40 tons)	3,300	5.00
One motor-boat (capacity 20 passengers)	Second-hand	

* One dollar (Malayan) is equivalent to 2*s* 4*d* sterling at the time of writing.

	Cost each: dollars *	Rate at which depreciated per hour: dollars
5. *Stone-rollers*		per hour
Seven Diesel rollers (9 to 12 tons)	27,000	3.00
One Diesel tandem (12 tons)	27,000	3.00
One Diesel roller (3 tons)	Second-hand	
6. *Stone-laying equipment*		
One Jaeger aggregate spreader	20,400	3.00
One Barber-Greene spreader and finisher	57,000	6.00
7. *Quarrying equipment*		
Two 30-in. × 16-in. crushers and one 36-in. × 9-in. granulator (one unit complete with elevators and screens) (50 tons/hour)	225,000	10.00
One high-speed Diesel engine (280 b.h.p.)	35,000	5.00
One air-compressor (500 cu. ft/min)	Second-hand	
Two air-compressors (each 300 cu. ft/min)	Second-hand	
Two wagon drills	Second-hand	
Two bit-sharpeners	Second-hand	
Miscellaneous jack-hammers, drill rods, and tungsten-carbide bits		
One standby portable crusher (20 tons/hour)	Second-hand	
One welding set (300A) (driven by crusher engine for building up worn-out jaws)		
8. *Bituminous mixing plant* comprising:—		
One batch-type mixer (20/25 tons/hour) electrically driven	240,000	10.00
One Diesel-electric generator (75kW capacity)		
One Diesel-electric generator (10 b.h.p) for starting up boilers when remainder of plant is not running		
Three 2,000-gal oil-fired boilers		
9. *Miscellaneous equipment*	Second-hand	
One portable welding set, Diesel driven (300A)		
One static welding set, driven off mains (300A)		
One gas welding set		
One battery-charging set		
One Fordson tractor with 6-in.-dia. core-cutter and mowing machine		
One boom crane (15 tons capacity)		

APPENDIX II

SPECIFICATION FOR QUARRY WASTE

The quarry waste shall comply with the grading shown in Fig. 22. The soil contained in the quarry waste shall have a Liquid Limit not greater than 32 and a Plasticity Index not greater than 8. The C.B.R. of a sample prepared and compacted at modified compaction and optimum moisture-content shall not be less than 50 after it has been soaked by complete immersion in water for 4 days.

The Paper is accompanied by twenty-one sheets of drawings and diagrams, from some of which folding Plates 1 and 2 and the Figures in the text have been prepared, and by two Appendices.

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* One dollar (Malayan) is equivalent to 2*s* 4*d* sterling at the time of writing.

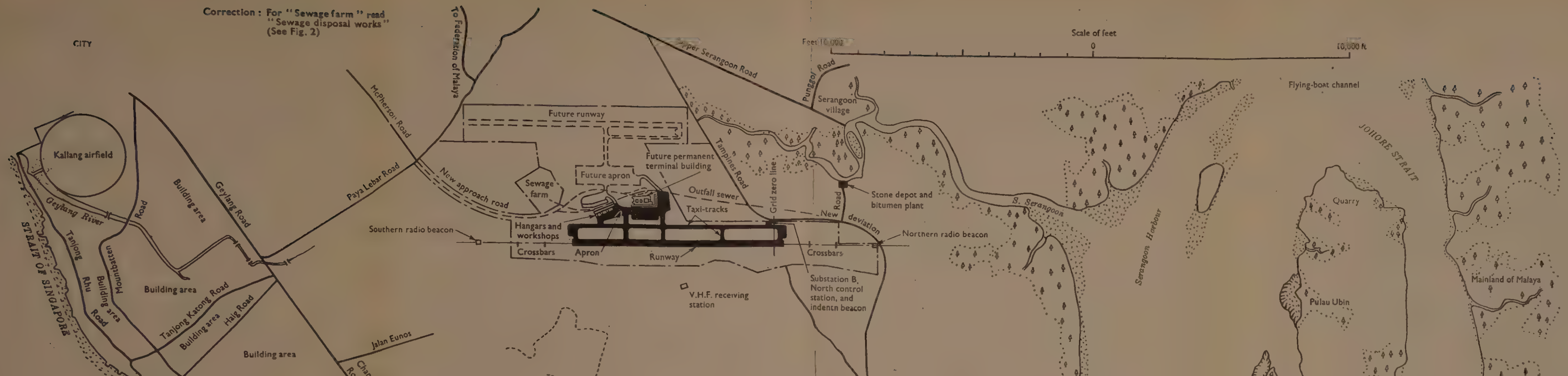


FIG. 1.- SITE PLAN

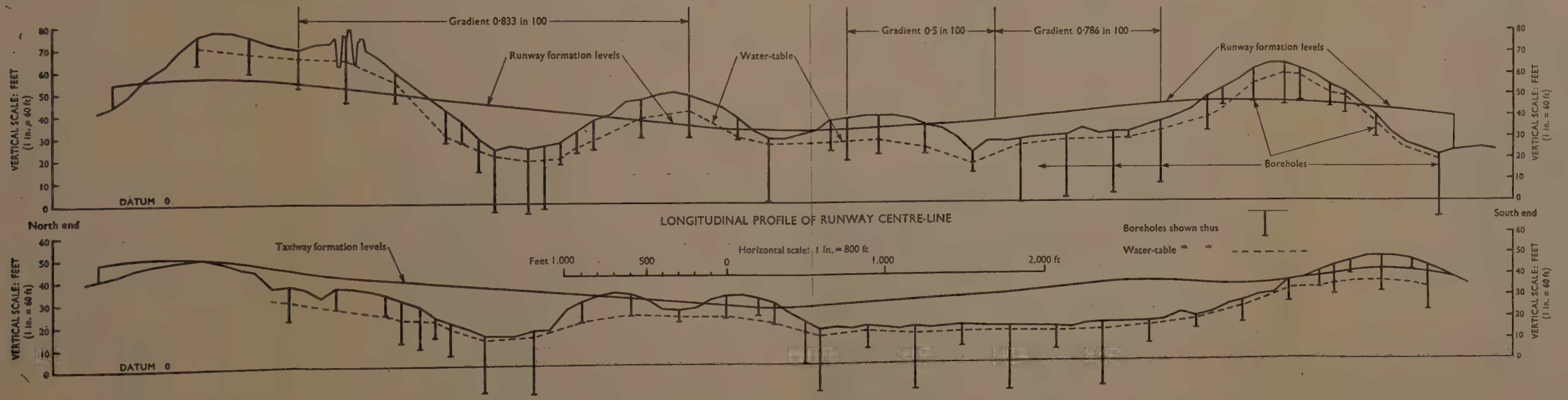


FIG. 3. - MAIN PROFILES

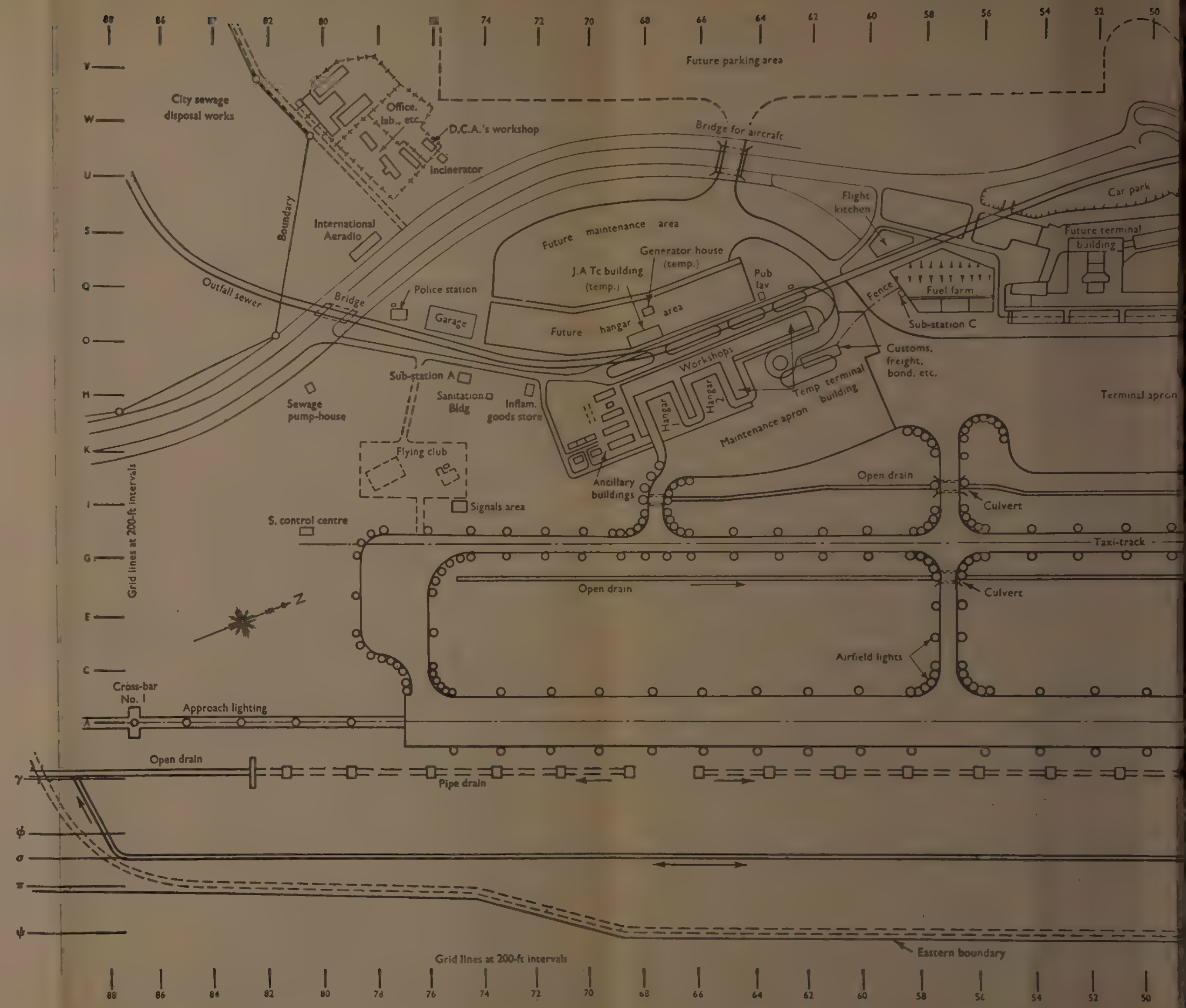
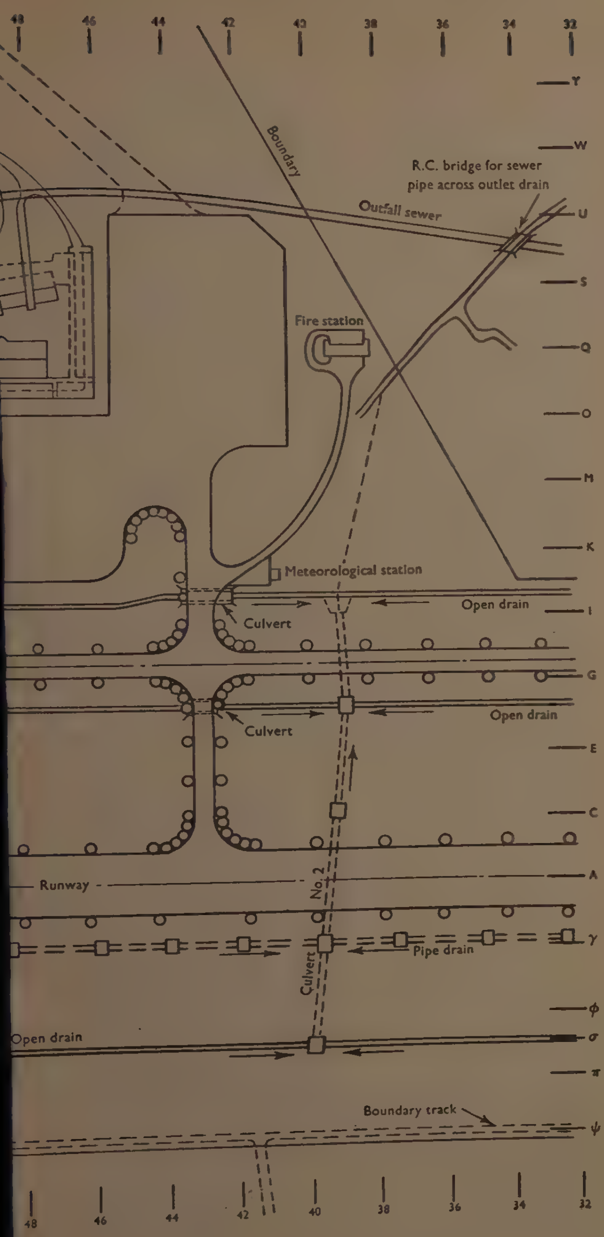


FIG. 2. - LAYOUT OF CENTRAL AREA

William Clowes & Sons, Limited: London



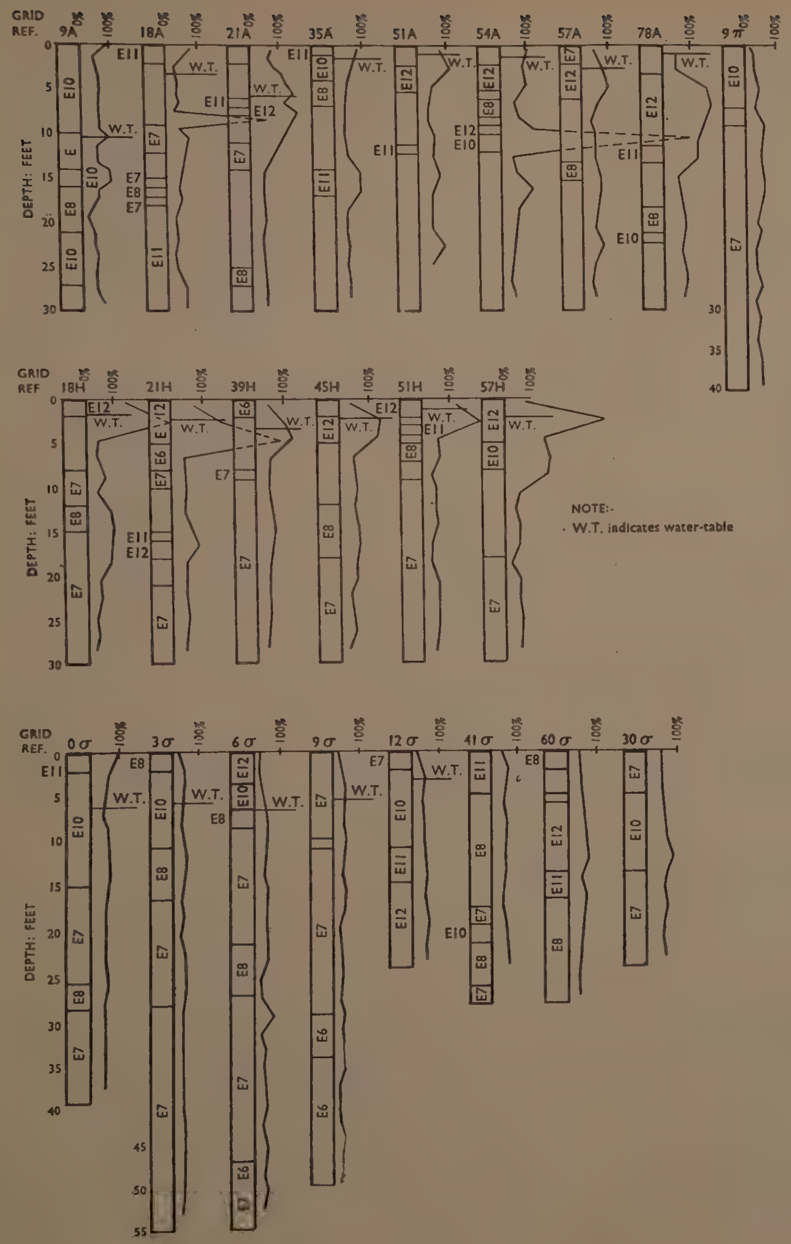


FIG. 4—VARIATION OF MOISTURE CONTENT WITH DEPTH

TABLE 1.—NATURAL C.B.R. RESULTS OF IN-SITU SOILS AT FORMATION LEVEL IN EXCAVATION AREAS

Location		A.0	A.3	A.6	A.9	A.12	A.27	A.30	A.64	A.68	A.71	H.35	H.73	H.77
Depth: ft		13 to 14	17 to 18	13 to 14	20 to 21	8 to 9	6 to 7	11 to 12	7 to 8	19 to 20	11 to 12	7 to 8	5 to 6	5 to 6
Depth of water-table below surface level		5′ 3″	10′ 0″	17′ 0″	10′ 6″	4′ 6″	11′ 3″	6′ 9″	9′ 0″	4′ 0″	3′ 9″	10′ 6″	10′ 3″	11′ 0″
Liquid limit LL		66·20	68·60	27·90	57·00	60·00	70·00	66·00	83·80	57·40	97·20	68·90	56·65	44·80
Plastic limit PL		33·50	25·50	15·60	31·20	20·10	30·00	30·00	33·10	21·80	37·96	31·28	27·25	24·00
Plasticity index PI		32·70	43·10	12·30	25·80	39·90	40·00	36·00	50·70	35·60	59·24	37·62	29·40	20·80
C.A.A. No.		E.10	E.10	E.7	E.8	E.10	E.11	E.10	E.12	E.8	E.12	E.10	E.8	E.7
Sieving: %	Retained on 10 mesh (U.S. sieve)	1·00	1·00	4·00	0·00	0·00	0·50	1·50	0·25	0·00	0·25	0·00	0·25	9·00
	Pass 10 mesh Ret. 60 "	56·50	50·75	51·00	22·50	7·50	17·50	49·50	24·75	0·25	0·25	8·50	31·75	40·00
	Pass 60 mesh Ret. 270 "	10·00	10·75	15·00	26·25	22·50	15·00	9·75	10·75	11·00	1·00	23·00	17·25	14·50
	Pass 270 mesh	32·50	37·50	30·00	51·25	70·00	67·00	39·25	64·25	88·75	98·50	68·50	50·75	36·50
Natural moisture content: %		26·95	26·20	17·30	33·90	33·38	32·70	24·81	30·55	27·05	45·35	35·15	28·06	33·55
C.B.R. values: % for 200 lb/sq. ft surcharge	Top	4.88	7·74	9·92	4·17	11·00	7·00	7·50	12·67	7·00	6·50	8·33	5·00	1·68
	Bottom	5·70	9·15	7·90	5·00	11·33	7·47	7·77	13·00	5·87	6·66	9·50	6·50	4·27
Wet density γ		121·00	120·40	126·10	115·40	116·40	114·80	122·00	114·30	124·00	111·70	111·60	112·20	116·75
Dry density γ_d		95·30	95·50	107·60	86·20	87·00	86·50	97·70	87·60	97·60	76·80	82·70	87·60	87·40

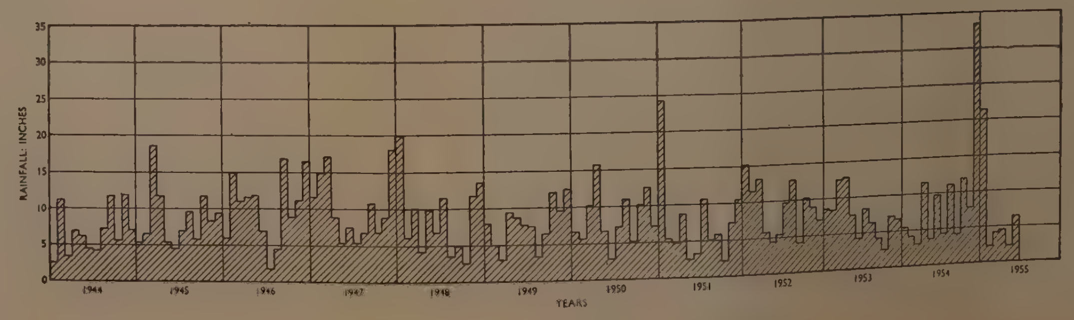


FIG. 5.—MONTHLY TOTALS OF RAINFALL
(Figures for 1944 and half 1953 supplied by Malayan Meteorological Service, Kallang Station)

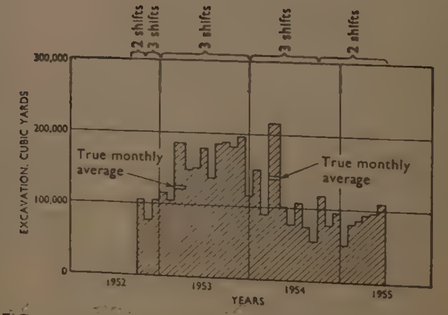


FIG. 6.—MONTHLY TOTALS OF EARTHWORKS

J. J. BRYAN

Discussion

The Author introduced the Paper with the aid of a series of lantern slides.

Mr Henry Grace (Partner, Messrs Scott and Wilson, Kirkpatrick and Partners, nsulting Engineers) said that the Author was one of the very few engineers who had en fortunate enough to be entrusted with the direct responsibility for the investigation, e design, and the construction of a major airport. Most engineers had to be satisfied th carrying out the investigation and design, and had then to entrust the construction some other authority, by whom it was carried out under their general supervision.

What had prompted the Singapore authorities to select the figure of 60,000 lb. for the uivalent wheel load for the design of a pavement? The task of airport engineers was fficult. After the 1939–45 war they had been told that they should design airports to pe with aircraft of the "Brabazon" class, having an all-up weight in the region of 0,000 to 300,000 lb., but a few years later they had been told that those types of rcraft were obsolete and that the upper limit of weight for passenger aircraft would be out 200,000 lb. That view had prevailed until recently, when they had been unexctedly told that aircraft which were likely to be built would have a weight in excess 300,000 lb. The designer of airports never knew what was coming next.

Mr Grace had recently made a study of the stresses produced by an aircraft weighing proximately 350,000 lb., supported on two 4-wheel bogie undercarriages and a noseheel. It had been interesting to see that, provided the C.B.R. of the subgrade at Singare did not fall below a value of 10, the design load of 60,000 lb. appeared to be quite equate to take aircraft of that weight. The selection of that figure, therefore, seemed have been quite appropriate; on what basis had it been made? Presumably the cision had been made before anything had been known about the heavier aircraft which re having to be provided for today.

Most engineers would be familiar with the work which the Road Research Laboratory d carried out to determine the equilibrium moisture content below a pavement, but the thor's experiments were probably the first to be carried out on the site in that conxion. In the tropics, subgrade materials were usually placed and compacted at about e optimum moisture content, but before being covered up they were usually exposed to e sun and dried out very appreciably. The Author's experiments had been carried out th his samples initially at approximately the optimum moisture content. It would ve been interesting if a few could have been started at a lower moisture content, to see hether or not they finished up at approximately the same moisture content as those hich had been started at the optimum. Since the completion of the airport, had the thor carried out any tests on the subgrade, and had any holes been excavated and any oisture-content tests actually made to see what had happened to the subgrade since the mpletion of the work? Mr Grace appreciated that digging holes in a single-runway rport was a difficult job, but it would be interesting to know what had happened to the bgrade since it had been placed.

A large number of moisture-content tests from below pavements had been made in the ited States of America, primarily on roads, and it had been found that there was very nsiderable variation and that it was almost impossible to predict what would be enuntered. Generally speaking, however, it had been found that the sandy soils reached equilibrium slightly below the Proctor optimum, whereas a clay soil seemed to pick up 3% above the optimum.

Any further information which the Author could give about his interesting experiments uld be valuable.

One of the major achievements to the Author's credit had been the decision to use bber-tired excavating machinery. The site was, speaking generally, a heavy clay site d there was 100 in. of rainfall a year, so that most construction engineers would probably nk twice before employing rubber-tired machines of the type which had been used, and

certainly in the United Kingdom Mr Grace imagined that their use would not be suitab The Author had very likely made his decision against the advice of many people in Malay It was quite clear, however, that the Author was familiar with conditions in Malaya. H decision had been courageous, and it was very encouraging to find that in practice it ha proved to be correct.

Mr D. S. Ferguson (Chief Engineer, Sir Bruce White, Wolfe Barry and Partner Consulting Engineers) said that the Author had moved 3,800,000 cu. yd of earth wi a very small amount of mechanical plant and had been able to keep that plant workin in a very efficient manner, for three main reasons. First, there was the very efficie drainage system which he had put in as the first work on the site. He had decided use very safe factors, and when Mr Ferguson had visited the site in the wettest of weath he had found that the whole drainage system worked admirably. The second reason w that the Author had consolidated and graded his earthwork as he moved it, and the thi had been the use of wheeled tractors. It had been interesting to visit the airfield and th visit a nearby earthwork which had been in progress at the same time, the building of road embankment, where tracked vehicles had been used. The haul had been rath shorter, but the time lost on the road embankment because of the weather had been man times greater than the time lost on the airfield.

The Author had been fortunate to be able to do all the work of functional desig investigation, research, and construction and finally round it off with a report to t Institution. Not many engineers had that privilege.

The Author had not given the total expenditure on the earthwork or the average ha for movement of the earthwork. If those figures were given it would be easier to asse the efficiency of his organization. He had not mentioned anti-malarial work, and would be interesting to know whether any special precautions had been taken in th respect, because mosquito-borne disease could be brought into Singapore and taken out Singapore to other countries.

Mr J. A. Skinner (Superintending Civil Engineer, Air Ministry Directorate Gener of Works) commented on the Author's remark that there had been plenty of other go sites in Singapore, which seemed to imply that by his standards the site which had be chosen was a good one. What in fact had been the total cost of the job divided by t number of square yards of pavement built? It was well known that Malaya was a difficu country in which to find sites for airfields, either in the hills or in the swamps round t coast, and it might be that by Malayan standards the site at Paya Lebar was as good could be found.

There was no doubt that the soils were difficult, but Mr Skinner had found it difficu from the Paper, without some sort of geological section showing the amount of each ty of soil, to say whether or not the very simple final answer—a C.B.R. of 10, a 12-in. bas course, and a 6-in. sub-base—was necessarily the right answer. He would like to kno more about the exact nature of the soils deposited to form the subgrade on which t Author laid the sub-base upon which the whole design depended. In the C.A.A. class fication the soils were average to poor. The Author said that he had put E6 and E7 depths of from 18 in. to 4 ft under the pavement, but it would be interesting to know little more about how they had been selected and compacted, and with what result.

Why had the Author introduced the intermediate compaction when dealing, in the ear part of the Paper, with the degree of compaction used in the initial density tests? M Skinner felt it was most important to realize that the C.B.R. method depended not on on the existence of the test itself but on the curves which interpreted the test result The curves which had been produced by the Corps of Engineers in the United States, a which had now spread round the world, were, of course, related to their modified Proct compaction. In the early days, when they had decided upon the weight of the hamm and the number of times it should drop, it had been to relate the order of the density in t pot to that which could be expected from the compaction equipment used in the fiel

e should therefore be circumspect when using the compactions without having the ictical evidence to adjust the curves to which the C.B.Rs were going to apply.

In the long run he noticed, however, that the Author had based his C.B.Rs on the ndard modified test and had established the general overall figure of 10%. Mr Skinner ught that that was a fair figure, but perhaps it tended to be on the high side, and he pported Mr Grace's suggestion that the Author might consider doing some in-situ B.R. tests to find out what the figure actually was under the pavement now.

It was difficult to be precise about the C.B.R. to be adopted on an airfield such as that question, where there was such a motley collection of soils that it was not possible to be e that the whole job from end to end would be anything like uniform.

On the whole he thought that perhaps the flexible pavement was on the thin side, rticularly when related to the importance of Singapore and the possibly greater loads of craft in the future. One feature of future aircraft might be that the tire pressures uld be higher. The effect of the 300,000-lb. aeroplane (mentioned by Mr Grace) on the vement would depend on the geometry of the undercarriage—how close the wheels were d what was the probability of interaction of the load from each wheel occurring within e pavement. On the other hand, the concrete was certainly quite thick enough, and a -in. total depth seemed extravagant. Perhaps the Author thought that the 8-in. ttom layer of the lower-quality concrete was acting as a sub-base for his top concrete t Mr Skinner felt that, having staggered the joints, the Author would have produced a ry strong double-slab pavement possessing a strength of something like double that of e flexible pavement down the runway.

Mr Skinner had been very interested to see the record of the experiments with the B.R. and the equilibrium moisture content, as established in the tests in the sealed conner, where the effect due to the suction of the soil had been measured. He felt that ere was an ever-present difficulty there. The work done by the Road Research Laborary established from certain constants of the soil the probable moisture content of the il at a certain distance above the water-table, but the great difficulty was going to be to tablish where in fact the water-table was, under equilibrium conditions. One might go far as to suggest that if there was an equilibrium moisture content under the pavement ere must be assumed to be an equilibrium water-table, which he thought was unlikely occur.

Mr F. H. P. Williams (Colonial Section, Road Research Laboratory, D.S.I.R.) conatulated the Author on the fact that he had managed to persuade the Government conrned to allow him to have his laboratory to carry out satisfactory tests for designing the rport and for controlling the work. Mr Williams emphasized that because he found at in many oversea territories Governments did not seem to appreciate the necessity of ving such control facilities.

The C.B.R. test, as Mr Skinner had already said, was an empirical test, so that great re was necessary in altering the dimensions of the specimen and the way in which the st was carried out. The Author had carried out tests on specimens half the height of a roctor mould, which was approximately 2½ in., and therefore the boundary effects were ping to be very different from those which would occur in a normal C.B.R. specimen. e had, however, used that method only as a comparison to see how the C.B.R. changed, d he could probably well get the answer by seeing what correlation there was between e C.B.R. values obtained from specimens of different sizes.

Engineers might feel that to wait 6 months for the answer was rather a long time, rticularly if they had to design and prepare contract documents for runways or other ojects. Mr Williams wondered whether or not the Author had thought of some of the ork which had been done at the Road Research Laboratory on soil suction. The strength a soil was dependent amongst other things on moisture content. However, for a given oisture content, small variations in soil type could produce appreciable variations in rength. By using the moisture content equivalent to a calculated soil suction the effect variations in soil type could be overcome. If some quick test could be produced to find

the moisture content equivalent to a given soil suction, which could be calculated by th height of the soil above the water-table and the type of soil, it should be possible to pro duce the specimen in a state such that an immediate test could be done, to give the answ much more quickly. The Road Research Laboratory was at the moment worki actively on that.

In order to control his earthworks and overcome the difficulties of the extremely hea rainfall which occurred in Malaya, the Author had designed the drainage system fir His plan was then to work the borrow areas so that they were well drained, to keep go haulways, and to compact the material as soon as it had been placed; the water would shed very quickly and what little water did soak in had wetted only the top inch or so the soil, and it had been possible to get on the job immediately afterwards. There w always a temptation in such work to press ahead during the actual rain. Shortly aft visiting the site at Singapore Mr Williams had gone to another job in a different territo not far away, and there the contractor, through trying to work in the wet, had got hi self bogged down and nothing could move for nearly 3 months.

Referring to the Author's decision to use pneumatic-tired tractors and scrapers, M Williams pointed out that the soils round the site, though clay, contained very abrasi sand, and in wet conditions very heavy wear would probably have taken place on the trac of tracked vehicles.

Mr E. H. Lewis-Dale (Civil Engineer, Air Ministry) asked if the Author had do k-value plate tests on the subgrade. Presumably he had not done so, because he ha stated early in the Paper that "The modulus of subgrade reaction equivalent to a C.B. of 10 was taken as being 200." The Author's reason for using flexible construction w presumably that he had been able to do the work with his own man-power, but Mr Lew Dale wondered whether, if it were a matter of comparison between concrete and flexib plate tests would not have been worthwhile.

With regard to the concrete, Mr Skinner had expressed the opinion that the concre was perhaps heavy, and Mr Lewis-Dale wondered whether, on the basis of a specifi strength of 4,000 lb/sq. in. at 28 days, even allowing for the fact that the Singapore co crete aged more rapidly than concrete in Britain, the values shown in the Author's Tab were not on the high side. What flexural strength had the Author in mind against h 4,000 lb/sq. in. compression test at 28 days?

The Author referred to the distribution of load from his 60,000-lb. wheel load, whi he had taken at 100 lb/sq. in. in showing the Boussinesq distribution. Mr Lewis-Da wondered whether or not the Author, in the design of his culverts, had not put the ca before the horse in taking an equivalent load, which was presumably the product of tw interfering loads, and whether it was not perhaps doing the job again to distribute t load on the Boussinesq theory. Mr Lewis-Dale did not know how one would get over tha unless one chose an aircraft typical of the 60,000-lb. wheel load and reapplied the Bou sinesq or other pressure-distribution values and saw what interference results they mig give.

Mr A. T. Sneller (Assistant Engineer, Messrs J. D. & D. M. Watson, Consulti Engineers) pointed out that runways in Malaya needed to be in only the one directio because of the prevailing winds, the Author had stated that the siting of buildings and t levels of runway and so on had been influenced by a city outfall sewer which ran across t edge of the site. It seemed surprising that what were relatively expensive buildings ha to be located by reference to an effluent outfall sewer which was not very deep under t main access road. One would have thought that in order to obtain the normally desir orientation of buildings in the tropics, that was on an east-west axis, the sewer might ha been realigned. Had that been considered? He believed he was right in saying that t size of the sewer was not adequate for its final capacity, so that the city authorities mig have been interested in enlarging it at the present stage.

On p. 388 it was stated that strip turfing had been provided to the sides of drains; w that sufficient and had any other protection been used? The Author said that grass gre

its own accord, but Mr Sneller had not noticed much grass over large areas when he had en there, and the slides with which the Author had introduced the Paper showed large eas of brown earth. Had any sheet erosion occurred in those areas, and had there been y serious gullying anywhere? On the far eastern boundary, as one stood at the present rminal building, he had noticed what appeared to be considerable gullying of the bank, d there appeared to be a digger realigning that bank and bringing it to a different ade. Was he right, and could the Author give the grades of those banks? Mr Sneller s interested because his firm was preparing a scheme for a new sewage-purification plant the other side of the city which involved the moving of about 1,250,000 cu. yd of cavation, so that any information which the Author could give would be helpful. They d been thinking over the question of spot-turfing the permanent slopes and possibly nulsion or hot-bitumen spraying of some of the surfaces of the temporary banks. The il was referred to as a weathered triassic shale by the geologist. Had the Author had y views on that matter and was he free to express them?

On the question of rainfall intensity, the Author referred to a figure of 6 in/hour for a ration of 20 min. From figures supplied to Mr Sneller's firm it appeared that over a riod of 30 years for which observations had been taken the highest rate of rainfall for min was about 6½ in. He did not suggest for a moment that the Author should have signed for that, but it would be interesting if he could give the frequency of 6 in/hour d say why he had chosen it. It seemed to be a little high, having in mind the large pacity of the drains and the fairly large capacity of the culverts. In the design of the rface-water drainage systems for the sewage-purification works a figure of 4 in/hour was ing considered as the maximum rate. It was true, of course, that with an airport one uld not have the runways flooded, whereas at a sewage works flooding would not matter much.

There had been a good deal of discussion at meetings of the Institution in the past year so on the question of capacity, and it occurred to him to ask whether or not any means measuring the flow from the airport drainage system had been incorporated. Any formation the Author could give on the high rates of rainfall in question would be very eful, even in the United Kingdom.

A previous speaker had asked what the cost of excavation had been. Roughing out the sts as far as the Author had given them, Mr Sneller thought the cost would be about 9 to 1$/cu. yd on the basis of labour and materials. It would be interesting to know hether that was a fair figure or whether there were a good many other things to be taken to account. Perhaps the Author could give the total cost per cubic yard.

The Author had mentioned that coconut trees would not burn when newly felled. Had had any rubber trees to deal with? About the same number of rubber trees would ve to be dealt with on the sewage-purification works site previously referred to, but they uld not be so fortunate in having such a large local population willing to cut them up d take them away.

The buildings at the airport were, for temporary buildings, extremely pleasant, very ht, airy, and cool, but he noticed that in the restaurant the venetian blinds were nearly ways down, because of the angle of the building relative to the sun's orbit. It was a mporary building, but the future permanent building also seemed to have a similar ientation, more or less north-south rather than east-west. Was it proposed to build the ture terminal on a north-south axis, or to turn it to an east-west axis so as to reduce the nount of direct sunshine coming into the buildings?

Mr Alfred Goode (Deputy Director of Works, Air Ministry) said he would be terested to know why the terminal apron had the form shown in Fig. 2 and what was the ason for the two re-entrant areas.

With regard to the "black top," the Author had stated that bitumen of 80–100 penetation had been used. That seemed to be a little high for use in Malaya, and it would em that a 60–70 penetration bitumen would be better. The Author had also said that to termine his bitumen mixes he had used the American Marshall test, but he did not say

whether or not he had carried out any check testing during the course of the job to see his Marshall figures were met in the actual mix. The mix had been designed for a stabili of between 1,500 and 2,000 lb. Mr Goode did not know that there was an upper limit the Marshall test, and thought that if 2,500 lb. could have been achieved presumably th would be better. The flow seemed to be a little high at 0·2 in. With such comparative high penetration bitumen and in a warm climate the flow might be kept down to abo 0·12 in. The wearing course had 6·25% of bitumen and 9·66% of filler. Had any troul been experienced with skidding on the runway, particularly in wet weather? Th percentages of bitumen and filler would give an extremely smooth finish.

Mr A. G. Gullan (Chief Superintendent Designs, Air Ministry Directorate General Works) referred to Fig. 3 and remarked that at both ends of the runway there was a dow ward slope. If Fig. 3 showed, as he thought that it did, the profile of the ground and t final surface of the runway formation levels, he could not see why a level approach ha not been adopted at both ends of the runway. It might even appear from the secti given, which he appreciated was a small one, more economical if, instead of taking upward curve at the right-hand side and then a downward slope, a level section had be taken at both ends, or even concave to the centre.

Mr R. J. M. Conibear (Engineer, Ministry of Transport and Civil Aviation) remark that the concrete parking aprons had been constructed in bays each 25 ft × 20 ft (in t case of the top layer) with a dummy joint in the middle, which made apparent bays 12 ft 6 in. × 20 ft. He had found that, in the case of concrete roads, bays larger tha 15 ft led to cracking owing to temperature gradients. Had there been any cracking in t Author's concrete bays?

Mr R. H. F. P. Wykes (Assistant Plant Development Engineer, John Laing Son, Ltd) referred to Appendix I, in which the Author had given a cost and depreciatic rate for the rubber-tired scrapers and tractors. Since that type of equipment had n been used in Singapore before, could the Author say what had led to the fixing of t economic life of the equipment. Had it been experience gained by the Public Wor Department in Malaya, or had it been obtained from authorities with extensive experien of such machines in the United States?

For what period of the work had the earthmoving plant been employed on double-shi work? Had the machines been affected by prolonged use, and in fact how many of t thirteen rubber-tired equipments had been in the workshop at, say, two-thirds wa through the earthmoving programme?

Where any of the breakdowns attributable to faults in the electrical equipment on t machines, or was it unaffected by the humidity in which it had to operate?

The Author, in reply to Mr Grace, said that at first it had been intended to constru the runway to a strength equivalent to a 100,000-lb. wheel load but about the time th that was being considered twin tandem bogie undercarriages had been introduced. As result the severity of the loads previously contemplated had been reduced; that led to t decision to construct a runway equal to a "B" Class runway in length and to Class 3 strength, by I.C.A.O. standards. That strength was equivalent to a 60,000-lb. wheel loa at a tire pressure of 100 lb/sq. in. None of the samples included in the C.B.R. experimen had been compacted at moisture contents drier than optimum. Of the undisturbed sampl taken from the runway and used in the experiments, it was more than probable that som when removed from the subgrade, were drier than optimum. From Table 6 it could seen that the moisture content of all those samples had increased while they were kept the sealed tanks. No samples had been taken from the subgrade after the pavement ha been laid to see how the moisture content was changing. It had been at one time t Author's intention to put cells under the pavement and observe the change in moistu content by electrical means, but as opinions on the value of such methods had varied an because of pressure of work due to shortage of staff he had not installed those cells. Befo

e rubber-tired equipment had been ordered the Author had visited many works to see it use under varying and trying conditions.

In reply to Mr Ferguson, the average haul was rather more than ½ mile taking into account ists and turns in the haulage tracks. The cost of excavating and removing topsoil was .30 (3s 0½d), excavating, hauling and spreading ordinary soils $1.00 (2s 4d), and com-cting 3½d per cubic yard. Those costs included the cost of operating plant, repairing it, d writing it off, but did not include the cost of administration, engineering supervision, rveying and setting out, and overheads. Before clearing and earthwork were started, ngs of men were put on to carry out the necessary drainage and oiling usually associated th antimalarial work. It was essential in such places as Malaya that antimalarial ecautions were commenced before any clearing or earthwork were started.

Mr Skinner had referred to the choice of site. So far as Singapore was concerned the e was a good one. There were others, as stated in the introduction to the Paper, but not any. Owing to the fact that the earthwork for the future maintenance area (see Fig. 2) d for an extension of the runway for 1,000 ft to the north, were practically completed d the cost thereof included in the cost of the job, and that the pavements for them ould not be constructed for some considerable time, it was nearly impossible now to give cost per square yard of pavement built as requested by Mr Skinner. In the hill to the rth-east of the site there were large deposits of sandy gravels containing a small quantity clay, and good clayey sands to the east of the strip for about one-third of its length. l Atterberg tests had been carried out on that part of the soils which passed the No. 36 eve. Those soils were the ones which had been used in the top layers of the subgrade. hey had *soaked* C.B.R. values varying from 12 to 20 for standard compaction, 20 to over 0 for modified compaction, and 14 to 33 for intermediate compaction. They were all 6 or E7 soils. Their dry densities ranged from 113 to 119 lb/cu. ft for standard compac-on and 120 to 131 for modified compaction. The intermediate compaction had been troduced in an attempt to form an opinion as to how a density more than that obtained y standard but less than that obtained by modified compaction would reduce the C.B.R. would be remembered that, as stated in the Paper, no information had been available as what densities could be attained in the field in Malaya. Since the discussion the Author ad studied a symposium on how the C.B.R. method of design for flexible pavements had een developed and was interested to find therein that tests had been carried out to find ut how the C.B.R. would be affected if the compaction aimed at in the laboratory could ot be attained in the field. In those tests the soil in the Proctor mould had been sub-cted to 55, 25, and 10 blows per layer. The curves which had been developed by the .S. Corps of Engineers were based on the C.B.R. of the soils and not on their modified roctor compaction; in fact, in the original traffic tests the C.B.R's of the soils under the avements tested had been taken on undisturbed samples removed from under the pave-ents after the tests had been completed. It was remarkable that the designs arrived at y the C.B.R. and C.A.A. methods gave results which agreed so closely, as could be seen om Table 4. The C.B.R. thicknesses were obtained from the curves in the U.S. Corps of ngineers' handbook. With regards to Mr Skinner's remarks about the height of the ater-table, it should be borne in mind that in soil there was water held by capillary ttraction of the soil and there might also be "free" water. It was that "free water" hich determined the height of the water-table. The free water could be removed by ubsoil drainage (providing there was sufficient fall and free outlets for the drains) and thus he height above which the water-table would not rise could be controlled.

At the time he made his tests the Author had realized that there might be some difference the C.B.R. values obtained, owing to the height of the samples under test not being the tandard height and he hoped that the Road Research Laboratory would carry out some esearch to find out how much that reduction in height of sample affected the C.B.R. esults obtained. It was the Author's impression that 6 months was not a long time to ait for results. Investigations took at least 4 months and if tests on the soil specimens ere commenced early and proceeded simultaneously with the survey the results would be vailable by the time that the airport layout was planned and certainly before money was

provided to commence work. It was the work which had been done at the Road Researc Laboratory which had inspired the Author in his experiments. Even if the ultimate equilibrium moisture content of a soil under a sealed pavement could be forecast he though it would be difficult to forecast the C.B.R., since for a given moisture content, the C.B. would, in the laboratory, vary according to the degree of compaction. That was th reason why the Author had tried to bring the soil to its ultimate moisture content and the take its C.B.R. in that condition.

A flexible type of construction had been adopted as a precaution against settlement i the filling, which had been quite high in places. The flexural strength assumed for th concrete was 700 lb/sq. in. or approximately one-sixth of its compressive strength. B referring to the U.S. Corps of Engineers design curves for rigid taxiways, aprons, etc., an using that flexural strength and assuming a K-value of 200 it would be seen that the thick ness required for a 60,000-lb. wheel load was 16 in., which was the thickness adopte Compressive strength had been specified in the contract because it had been easy to chec by cutting cores. The Author, in applying Boussinesq's distribution, had taken th 60,000-lb. wheel load at its face value in the same way as he had done in the design of th runway.

The cost of laying a sewer on a new line would have added greatly to the cost of th airport. In addition the time which would have been taken to complete the negotiatio would have been prohibitive. Up to the time the Author had left Singapore there ha been no slip of consequence on the main open drains and the strip turfing was satisfactory As stated on p. 388, intercepting drains had been constructed at the top of the banks o main drains and the water flowed from the intercepting drains into the main drains throug 6-in. pipes placed at 75-ft intervals (Fig. 15). Without the small intercepting drains a the top of the banks slips would certainly have occurred. During the construction, onl comparatively small areas had been covered with top soil and the main area had not bee covered until 1 month before the opening of the airport. The grass had grown well o those small experimental areas—of its own accord, even on the slopes. The banks to th east of the airport had not been completed by the time that the airport was opened. The were sloped at 1 in 7 for aviation purposes in order to comply with I.C.A.O. requirement In Malaya it was better to make a bank as steep as it would stand up—frequently on road as steep as ½ to 1. On steep slopes, contour drains and bunds should be provided and possible a running type of plant should be grown. They could frequently be seen on rubbe estates in Malaya, in fact some could be seen in the young rubber just to the north of th airport. Strip turfing was better than spot turfing. From 28 years' experience in Malaya the Author did not think that spraying with bitumen was essential. He had seen it used however, on the Snowy Mountains scheme in Australia. In Malaya, 2 in. of top soil wa generally enough to promote a growth of grass. In Singapore, the soil on the western par of the Island was generally the result of the decomposition of quartzites and shales and o the east the decomposition of granite. The dividing line crossed the airport site about quarter of the way up the runway from the south end. The rainfall records showed tha for a storm lasting 20 min the intensity could reach 6 in./hour. Exceptionally heavy rain had occurred at the end of 1954 and the beginning of 1955 and by observing the drains a peak periods of rainfall it had appeared that the drains were just about the correct size No instruments for measuring run-off had been installed but that could easily be done if th money were provided. It appeared to the Author that more knowledge of coefficients o run-off was required, just as much as more knowledge of rainfall. Rubber trees had bee felled by dozer and sold at good prices after calling for bids. By felling with a dozer th roots were pulled up at the same time as the trees were felled.

The Author had had nothing to do with the design of the permanent terminal building and so could not comment on it.

The reason for the two re-entrant areas mentioned by Mr Goode had been to make i difficult for an aircraft on a taxi-track to foul an aircraft parked on an apron.

The 80/100 penetration bitumen had been used because it was thought that it would b less likely to crack than a harder bitumen. It was the standard practice in the Souther

ates of the U.S.A. to use 80/100 penetration or softer bitumen. Since those States perienced high temperatures in the summer it had been thought that what was suitable ere would also be suitable in Singapore. Check tests had been carried out during nstruction and the desired Marshall stabilities had been attained. Up to date there had t been any instances of skidding on the runway. It had been feared that if the flow was pt down to as low a figure as 0·12 in. the pavement would be lacking in flexibility.

The final grading of the runway had been adopted as a result of making many attempts ith different gradings to reduce the quantity of earthwork involved. The one most onomical, bearing in mind the requirements of the site, had been adopted.

The size of the concrete bays was the same as that adopted on an extension to the parking ron at Kallang Airport, where, apart from a few slabs which had cracked for some unown reason within 24 hours of being laid, no more slabs had cracked since.

The economic life of the equipment used had been estimated from information acquired the United States. From Table 11 it could be seen that up to the end of May 1955 most the earthmoving machines had worked nearly 9,000 hours. The estimated life was),000 hours. The machines had worked three shifts from early 1953 until the end of 54, when they had been put on two shifts. Machines had been frequently in the workops for running repairs and at the end of the job had required to be completely taken wn and thoroughly overhauled. The electrical equipment had not suffered unduly cause of the humidity of the climate. It had been necessary, however, to renew tteries more frequently than anticipated.

The closing date for Correspondence has now passed. No contribution has been ceived.—Sec.

RAILWAY DIVISION MEETING

Thursday, 26 April, 1956

Mr M. G. R. Smith, Member, Chairman of the Division, in the Chair

The following symposium of Introductory Notes was presented for informa discussion and, on the motion of the Chairman, the thanks of the Division wer accorded to the Authors.

Railway Paper No. 62

MECHANIZED AND MOBILE GANG MAINTENANCE OF TRACK

Three Introductory Notes by

*** Harold Hedley Robinson, A.M.I.C.E.,**

Idris George White, A.M.I.C.E.

and

John Roy Hammond, M.B.E., B.Sc.(Eng.), A.M.I.C.E.

Eastern Region

by

H. H. Robinson, A.M.I.C.E.

The traditional method

UNDER the traditional system of track maintenance each length gang dealt with a fixed length of railway and was responsible not only for maintaining the top, line level, packing, and components of the track itself, but also looked after such off track duties as drainage, fencing, repairs to minor roadways, maintenance of cesse and slopes, and so on. This system had been used throughout the country fo nearly a century and only within the past 20 or 30 years have two modifications been noticeable:—

(1) On certain second main and branch lines, the "trolley gang" system hac been introduced. In this method certain gangs were amalgamated anc were given a longer length to maintain, with the assistance of a moto trolley to transport men and materials to the point at which the work lay The plan showed economies on paper (though the saving in the gangers differentials was partly offset by the differential which was paid to a "patrolman," who was appointed to assist the ganger in walking hi length). A further item which tended to offset the economies was, o

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Mr Hammond is District Engineer, Wolverhampton, Western Region.

course, the purchase and maintenance of the trolley, together with the provision and maintenance of the necessary signalling equipment. Despite these items, the system as a whole usually showed a paper saving and was widely applied on various categories of line. In practice, it was found to have grave drawbacks, chief among which was the time wasted in getting the men to their work, and the difficulty of supervising the work if more than one job had to be done at a time. Under this system, the ganger was still responsible for the whole of the maintenance work on his length.

(2) Again over the past 20 to 30 years, attempts have been made to mechanize certain of the operations performed by the length gang which had hitherto been performed almost entirely by manual methods. Early instances of such attempts were the use of pneumatic power for track tampers, and the application of petrol engines to portable ballast screens. In the first instance, these machines were intended, not to economize manpower as such, but to enable these operations to be done more efficiently. Since those days the progress of mechanization has been rapid, and all are familiar with the degree of mechanization which is being reached in certain maintenance operations today.

Necessity for change

Even before the second world war, the effects of rising wage levels outside the railway service and the attraction of other industries were making themselves felt, and difficulty was being experienced in maintaining the strength and skill of the length gangs. Since the war, with wages in outside industry rising at an unprecedented rate, the position has deteriorated rapidly, and moreover it is now necessary to maintain the railways in a proper state to carry electrified services at generally higher speeds, and probably more frequently than before, with a reduced labour force.

The answer to this urgent problem is being sought along several lines of enquiry, and it is the purpose of this Note to describe what has been done on the Eastern Region in one direction.

Mobile-gang system

The decision to introduce the mobile-gang system as distinct from the trolley-gang system was taken in order to fulfil two objects:—

(1) To ascertain whether even more effective use could be made of the available manpower.

(2) To pave the way for the introduction, on a systematic basis, of mechanical aids to permanent way maintenance.

As an experiment, a section of the important branch line from Hitchin to Cambridge (Fig. 1) was selected. This line is Class B1, and the present train service over it provides the quickest route from London to Cambridge. It is a double-line route through undulating country. The foundation is mostly chalk so there is good natural drainage.

The experiment was put in hand over this length between the 45 mile-post and 55 miles 506 yd. This length of 10 miles 506 yd was originally maintained by a ganger, subganger, 2 patrolmen and 14 lengthmen—a total of 18 men. They had been provided with a petrol-driven trolley and trailer for the transport of men and their tools.

In the experimental scheme, the length of about $10\frac{1}{4}$ miles is divided into three

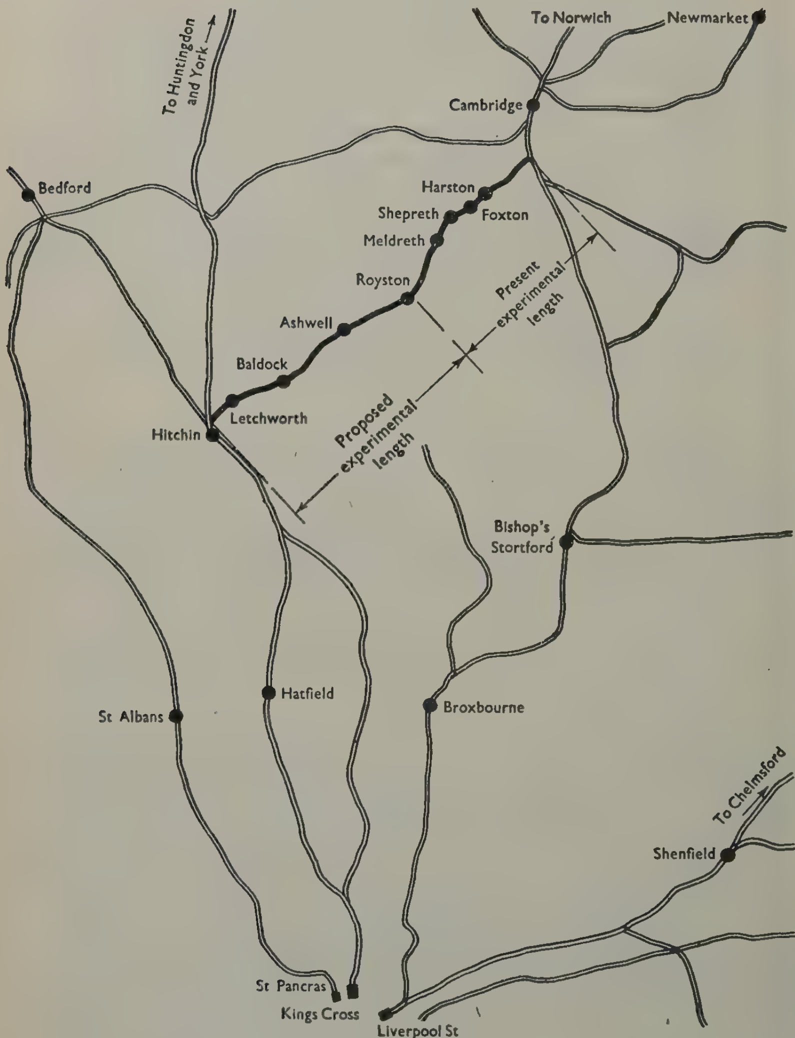


FIG. 1.—EASTERN REGION, CAMBRIDGE BRANCH

engths of 3 miles 14 chains, 4 miles, and 3 miles 14 chains (see Fig. 2) maintained by angs of 4, 5, and 4 men respectively, so far as the on-track work is concerned. The "off-track" work for the whole length is done by a mobile gang of 5 men, based on hepreth. The total number of men is, therefore, 18, the same as under the old ystem. The cost of 3 gangers is additional, partly offset by a saving of 1 subanger; but in this respect the new scheme is evidently more costly than the old, at resent.

The outer edge of the ballast shoulder was fixed as the division of responsibility

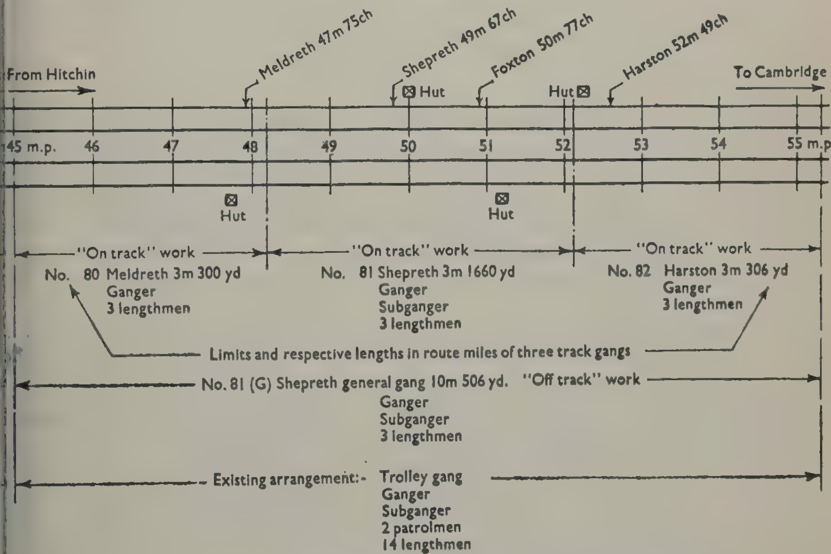


FIG. 2.—CAMBRIDGE BRANCH—MANNING 45 M 0 YD—55 M 506 YD

between the length gangs and the mobile gang. In yards, of course, the track is looked after by the length gangs and they maintain the road surface of level crossings out to the line of the gates. It will be seen, therefore, that the length gangs deal with the whole of the maintenance of the track and ballast, and the mobile gang with the maintenance of drains, cesses, grass verges, fencing and roadways, and the cutting and burning of grass on slopes; they also load up scrap and look after all permanent-way huts.

It will be appreciated that very close co-operation is required between the length and mobile gangs; and when such schemes are being detailed, the necessity for having gangers and subgangers who are ready to co-operate with one another (particularly in the case of the mobile gang) must be stressed, the personality of these men being closely considered.

Progress achieved by mobile-gang maintenance

The revised arrangements were introduced in September 1954. Towards the latter end of last year the experimental section was specially examined with a view

to assessing the results of the year's work, and it was then found that all lengths had improved, the average improvement on the usual length-marking basis being 5 marks. This was distinctly encouraging; and recently one of the length gangers had expressed his approval of the new set-up and quoted, among other things, the much greater facility with which repairs to such items as fencing and roadways were now carried out.

On the strength of this, it is proposed to extend the experimental length over the remainder of the Hitchin–Cambridge Branch, i.e., for a further $12\frac{3}{4}$ miles, to the extent indicated in Fig. 3.

It should be pointed out that the Eastern Region experiment is no more than a modification of the present system. It does not embody any radical departures from tradition as do, for instance, incentive schemes.

Mechanical aids

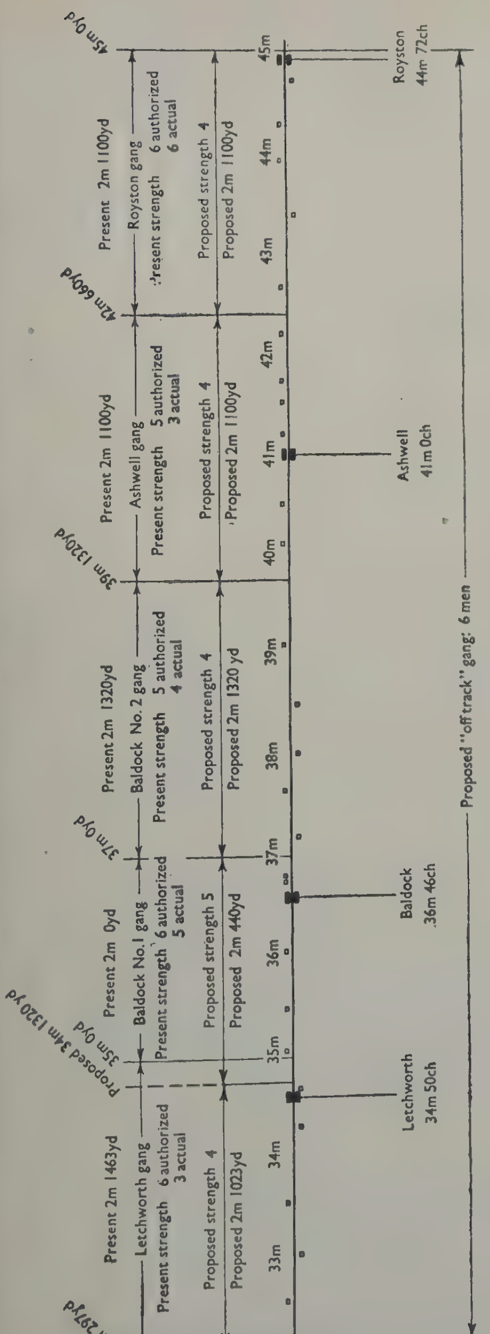
The second of the objects of the new system of maintenance, i.e., the provision of mechanical aids to permanent way maintenance, is still in its infancy. This experiment is also being tried on the Hitchin–Cambridge Branch. The only mechanical tools used on track maintenance are the Matisa on-track tamper, two Matisa screwing machines for chairscrews, and a John Bull rail-drill. These machines, as will be appreciated, are not restricted only to the experimental length; they are used thereon when the gangers ask for them and at such times as the Permanent Way Inspector can arrange.

The mobile gang is equipped with a mechanical scrub-cutter and delivery of a Colwood motor hoe is now awaited; an Allen motor scythe has been used by this gang during the spring and early summer but is not part of the gang's equipment, having been borrowed from another district. Although the scheme, as originally drafted, contemplated the provision of a light road motor vehicle for transport of the men and their tools, this has not hitherto been found necessary. The scrub-cutter was not delivered until recently, and before its arrival the mobile gang managed to use the ordinary train service for transport. With the advent of the scrub-cutter and still more when the motor hoe is delivered, however, circumstances will be very different and the road vehicle will become very desirable. As indicated above, it is proposed shortly to extend the scheme, and the single road vehicle will probably cover the needs of the mobile gangs over the whole Branch.

To sum up, therefore, the scheme on the Eastern Region, though small in extent, was very carefully organized and has been under close scrutiny by the District Engineer. This careful follow-up has paid dividends, for the standard of maintenance on the branch has improved to a marked degree; the men find that it is of benefit to them; and a sound basis has been laid down for the extension of the scheme to other lines and districts.

The Matisa ballast tamper, as mentioned above, is from time to time employed on the experimental length, and both the District Engineers in the London Area of the Eastern Region are relying more and more on this machine to overcome their difficulties with regard to manpower. In this connexion it may be of interest to note that, by the use of the Abtus sighting boards devised for measured shovel packing, a greatly improved standard of longitudinal and cross level is being obtained by the Matisa machine, and satisfactory maintenance packing is being carried out without the necessity of lifting the track.

By the new procedure the high spots on the length to be tamped are marked as usual, say 120 ft apart. The sighting board is set up on the second high spot, the



TOTALS

	Present	Proposed
Lengths	Five	Five
Strength	Authorized: 28 men Actual: 21 men	On track: 21 men Off track: 6 men

Mileage 12m 1463yd

FIG. 3.—CAMBRIDGE BRANCH. CAMBRIDGE JUNCTION TO ROYSTON. PROPOSED REGROUPING OF LENGTH GANGS

target board being placed at the first. The intermediate board is then moved along the rail to fixed points about 12 ft apart, at which obstructionless jacks have already been placed. At each point the rail is raised by the jacks until it is about ¼ in. high, and the jack is then struck with the handle, so as to settle it firmly in the ballast, until the rail is at the correct level. The level of the opposite rail is at the same time corrected by the use of the cross-level gauge. When the jacks are all in position and the rail levels corrected, the machine commences to tamp. As it moves forward the jacks are removed, a pair at a time, trollied forward, and refixed ahead of the last pair previously fixed. Jacking and tamping are, therefore, carried on simultaneously.

After the passage of the machine, the top will be found to be of the order of 88–90 by normal standards of marking.

In a 5-hour possession at night, using a team of 9 men, 400 to 440 yd of track can be tamped.

The Matisa machine, valuable though it is, suffers from several drawbacks:—

(1) It requires possession of the line.
(2) It cannot deal with switch-and-crossing work.
(3) It cannot tamp sleeper beds where such obstacles as cables, connexions to impedance bonds, and the like exist.
(4) Matisa tamping will not stand long where there is 5 in. or less of ballast below the sleepers.

For lines with heavy traffic both night and day, and to deal with switch-and-crossing work, and also in an attempt to cope satisfactorily with lines where the depth of ballast is very restricted, the Eastern Region has selected two of the recently introduced makes of "individual" electric tampers, the "Vibromax" and the "Bosch" (both described in Railway Paper No. 60) for experiment.

This does not represent the first experimental work done by the Eastern group of lines in the way of mechanical tamping; for Ingersoll-Rand and Consolidated Pneumatic machines were used on the former L.N.E.R. lines around Leeds as long ago as 1945, and so was a French machine, the Collet. This was an electric tamper, and gave promising results at that time.

In the latest experiments, the "Vibromax" tampers were primarily intended for work on plain line, and the "Bosch" for switch-and-crossing work.

The Eastern Region's experience to date is too short for any final conclusions to be drawn. Early results with the "Bosch" tamper have been promising, and the tendency of this machine to break up slag ballast is being countered by the substitution of 120-mm tamping heads for the 80-mm heads originally supplied. Certain electrified track tamped by the "Vibromax" machines has stood up extremely well; but unfortunately many lengths on these electric lines have very shallow ballast, and it is not yet certain that either the "Bosch" or the "Vibromax" machines will perform satisfactorily in situations like this.

London Midland Region
by
I. G. White, A.M.I.C.E.

Introduction

The traditional method of carrying out track maintenance in Great Britain is by the employment of static length gangs who are responsible for maintaining a fixed

ngth of track. This has resulted in a spirit of pride in the length of track main-ained by the various gangs, and has also produced marked variations in the relative andards of maintenance.

Railway engineers have been experimenting with mobile maintenance schemes for everal years, generally choosing branch lines on which power-driven rail trolleys ould be used to convey the gang from site to site. These schemes worked with arying degrees of success, the main criticism being that they achieved only a atchy standard of maintenance.

During the years following the 1939–45 war the quality of labour recruited for ack work deteriorated, the position being particularly acute in industrial areas. here were heavy arrears of track maintenance to be overtaken before pre-war peeds could be restored over trunk lines. Hence, redeployment of labour available certain areas was considered as a first step. Volunteers were called from the sser industrial areas to move to the known black spots, and dormitory coaches, hostel accommodation, were made available to them. Although this arrangement itially achieved a measure of success it eventually faded because, owing to the ousing shortage, men were unable to move their families. At this time machines daptable to permanent-way maintenance were rapidly being developed and the ea of equipping a mobile maintenance gang with such mechanized equipment was onsidered.

Before a scheme of mobile mechanized maintenance of track could be undertaken was necessary to have the full co-operation of the staff, because with dissatisfied aff any mechanization experiment would fail. It was also necessary to find out hat mechanization could and could not do. Hence, it was decided that pilot xperimental mechanization schemes should be introduced in various Regions.

In the London Midland Region, after considerable investigation, it was decided introduce a mobile mechanized maintenance scheme in the Birmingham area.

he Sutton Coldfield mobile mechanized maintenance scheme

This scheme was brought into being on 1 January, 1952, and was introduced cover the maintenance of a Section Inspector's complete area, which consisted of 7 miles of category "C" track and 23 miles of sidings, extending over a geographical ileage of 53 miles. The authorized manpower of the static gangs, based on the M.R. manpower formula, was 90 men.

When considering the formation of special mechanized gangs for maintenance it evident that there must be efficient arrangements to get men and equipment to e site of work quickly. It was decided to split the 53 geographical miles into ree parts, ranging from 15 to 18 geographical miles each (and with centres at itton Coldfield, Walsall, and Lichfield), so that mechanized gangs could be collected om the vicinity of each centre and conveyed by lorry to the site of work.

Although the authorized static length gang manpower was 90 men there were 21 cancies at the time the scheme was introduced. The total number of men based each area was to be 25, or a total of 75 men for the whole scheme. At the time was thought that by splitting the scheme into relatively small areas, and by troducing several small gangs of similar construction, competition would be stered and a spirit of pride in length would still be in evidence.

The duties undertaken by the gangs and the equipment provided are listed in ble 1.

TABLE 1

			No. of men
Length "A" (15–18 miles)			
Patrolling: Each man 5–6 miles		Subgangers	3
Point-oiling		Oiler	1
Gang No. 1: fettling and gauging		Ganger Subganger Lengthmen	1 1 3
(a) Duties:	Gauging and chair fastenings. Replacement of broken fishplates. Tightening fishplate bolts. Expansioning. 1-year cycle.		
(b) Equipment:	1 Matisa screwing machine. 1 rail adjuster.		
Gang No. 2: alignment and packing		Ganger Subganger Lengthmen	1 1 4
(a) Duties:	Alignment and opening out and packing. (Shovel and M.S.P.) Help for 13 weeks with the Matisa tamper. 1-year cycle.		
(b) Equipment:	2 Kango tampers. 1 Abtus track liner. 1 M.S.P. outfit with extra number of void-meters. 1 Matisa tamper (part use). 1 generator.		
Gang No. 3: ballast-cleaning gang		Ganger Subganger Lengthmen	1 1 3
(a) Duties:	Ballast cleaning. Weeding to limits of cess. 7-year cycle.		
(b) Equipment:	1 modified Abtus ballast cleaner.		
Gang No. 4: fencing gang		Ganger Lengthmen	1 3
(a) Duties:	Repairs to fences, hedges, firebelts, mowing, drains. 1-year cycle.		
(b) Equipment:	1 Allan motor scythe. 1 Gem rotary hoe. 1 Tarpen hedge trimmer.		
Transport		Driver 1 lorry (30 cwt)	1
		Total staff	25
Length "B" Same staff and equipment as for "A"			
		Total staff	25
Length "C" Same staff and equipment as for "A"			
		Total staff	25
	Grand total of staff for $52\frac{3}{4}$ miles		75

sults

Subsequent length marking revealed that there was no significant change in the ndard of track maintenance during the period the scheme had been in operation, t this may be taken as an indication of the success of the general principles when nsidered in the light of the difficulties encountered. The latter fell into two ain categories:—

1. *Fluctuations in manpower.*—Since the scheme was introduced the full number men to work it had never been available. Also variations in the numbers had curred daily making proper planning and organization difficult.

2. *Lack of flexibility.*—The scheme, as planned, was too rigid to allow all the work be covered to the best advantage, particularly in view of item (1). There were men available to deal with minor repairs on the spot and this entailed a waste of ne in moving one of the mobile gangs to undertake this work. Hence, it was cided to amend the original scheme and a revised one was brought into operation March 1953.

nended scheme

The amended scheme provided for the whole section to be split into two sub-ctions, manned throughout with length gangs and with two mobile mechanized ngs based on Sutton Coldfield and Lichfield respectively. The length gangs were ade by extending the traditional length gangs and manning them with "skeleton" ngs; the strength of the mobile gangs at Lichfield and Sutton Coldfield being men and 11 men respectively.

The revised scheme worked with a greater degree of success than the original one, spite of manpower shortages, which resulted in the Sutton Coldfield mobile gang ing entirely absorbed in filling length-gang vacancies, but this was countered by ansferring the home station of this gang to Walsall where limited recruiting of bour was possible. Length marking in the following 2 years has shown a gradual crease in the standard of maintenance.

nclusions

The Author feels that future trial organizations could be subdivided into two tegories:—

(1) Lines where traffic conditions, either by day or night, or seasonally, will allow "on track" equipment such as the Matisa tamping machine to be used to such an extent that, following its use, the track can be left for months at a stretch without attention.

This could be truly called mechanized maintenance.

(2) The concentration of labour force in turn on the different lengths of a section according to work content, providing adequate means of transport and portable plant. This could be called mobile maintenance.

It is suggested that the following factors are essential to ensure the success of mechanized maintenance scheme:—

(*a*) The traffic conditions already suggested.

(*b*) The development of a suitable form of track which is capable of being maintained by mechanized aids, e.g., concrete sleepers with a suitable fastening and long-welded rails.

(*c*) An intelligent technical person in charge of the scheme, who is not only competent to assess the requirements of the work but has knowledge of the

limitation of the plant at his disposal and its best method of operation, and who regards the scheme with enthusiasm.

The Author suggests that the following factors are essential to ensure the success of a mobile maintenance scheme :—

(*a*) The Permanent Way Inspector shall be an intelligent person competent to assess the real requirements of work with a measure of enthusiasm for the scheme.

(*b*) There shall be ready means of transporting men and tools, either by motor transport where the road layout suits, or by rail—either by normal passenger service where sufficiently frequent, or by rail trolley.

(*c*) At least a "skeleton"-length manning is needed to cover inspection, lookout, and hand-signalmen's duties for other departments' minor mishaps and such incidents.

(*d*) The line shall be put into reasonably good order before the scheme is introduced, especially if it is one designed to overcome a severe manpower shortage.

Western Region

by

J. R. Hammond, M.B.E., B.Sc.(Eng.), A.M.I.C.E.

General description

The Oxford, Worcester and Wolverhampton Railway was constructed between 1850 and 1854, passing through agricultural country between Oxford and Stourbridge, after which, to Wolverhampton, it more or less forms the western boundary of the Black Country. The part of the line over which the Experimental System was tried commenced just north of Oxford and included Worcester. It is a double line, Category B1 route, with locomotive depot, repair shops, carriage and wagon shops, sheet shops, etc., located at Worcester. For the rest, there is quite heavy fitting work and a busy yard at Honeybourne, but otherwise it is rural in character. Approximately thirty freight and twenty-six passenger trains run in each direction every 24 hours, with speeds up to 70 m.p.h. There is a tunnel $\frac{1}{2}$ mile long between Honeybourne and Campden, and there are water troughs near Charlbury.

Maintenance history

Originally the line was maintained by static length gangs covering 2 to $2\frac{1}{2}$ miles of double track. In 1933 the majority of these gangs were amalgamated to form lengths of approximately 5 miles, with an establishment of 9 men (average); that was the position immediately prior to the introduction of the Experimental Scheme. The authorized staff establishment is represented by 0·85 men per mile, but the actual man-power, due to shortage of staff, is in the neighbourhood of 0·68 men per mile.

Introduction of the Experimental Scheme

The scheme was introduced in June 1951 on two parts of this route, one located on the Worcester permanent way section, and the other on the Kingham permanent way section. The same basic arrangements applied to both sections, and consisted

the main of reducing the static length gangs to a ganger with two men and rming from the remainder large mobile gangs with large gang trolleys to get them om place to place. At Charlbury (water troughs) and Campden (tunnel), an lditional man was attached to the static gangs because of special local conditions.

orcester permanent way section

The first part of the Worcester section over which the Experimental System was ied, covered gangs Nos 78 to 81 inclusive, with approximately 18½ route miles of uble track and 6½ miles of sidings. The authorized establishment for this portion as 35 men plus 2 roadmen, making a total of 37. Under the revised arrangements, mobile gang of 11 men was formed, leaving on the lengths four gangs of 3 men us 2 roadmen, giving a total of 25.

In April 1953, the experiment was extended to include the Honeybourne length ng which was transferred temporarily from the Stratford-on-Avon permanent way ction, and also two length gangs at Worcester. The authorized establishment for is revised portion was 57 men, the actual total of 49 being made up of 25 men in e mobile gang and 24 in the 7 static length gangs. This covered 22½ route miles d 15 miles of sidings, and included a very heavy area of fitting work and yards at orcester, and large and important junctions and yard at Honeybourne.

Conditions now varied considerably over the area, and it was this out-of-balance the concentration of work which made the organization of maintenance and the ogramming of the work very difficult. As a result, deterioration in the maintenance of fitting work at Worcester and Honeybourne in particular led to the ncellation of the scheme on this section, and in October 1954 the original static ngth gangs were re-established and the experiment was concluded.

ingham permanent way section

Initially the scheme was applied to gangs Nos 71 to 75 inclusive, but in November 51 this was extended to include No. 76, so that the whole of the main-line portion the Kingham section was included, covering 30 route miles of double line and miles of sidings. The authorized establishment was 54 men, but a mobile gang 25 men with 2 trolleys and 6 static length gangs totalling 20 men were formed to ve a total of 45.

rganization of work

Below is given a very broad subdivision of the duties of the length gangs and ose of the mobile gang, but it will be appreciated this is very flexible and the emands of the moment can be met quite easily.

Duties of length gangs	*Duties of mobile gang*
Examination of length	Major repairs
Measured packing	Major lifting and slewing
Joint maintenance	Assist Matisa tamping machine
Tightening of fastenings	Adjusting rail creep
Oiling fishplates	Ballast cleaning
P. & C. maintenance	Hedging and fencing
Point oiling	Ditches and track drainage
Grass cutting, weeding, etc.	Assisting in grass cutting, etc.
General light repairs	Assisting relaying
Snow and fogging duties	Following up relaying.
Assisting relaying.	

Examination of lengths (5 miles) involved a considerable proportion of length-gan man-hours and rendered the effectiveness of any small gangs open to doubt. It wa the length ganger's duty to keep his inspector fully informed, particularly where h required assistance from the mobile gang. It was up to the inspector to assess th priority to be accorded to such requests and with his own close knowledge of th section, he was able to programme the mobile gang's work 3–4 weeks ahead.

In the initial stages of the scheme, very intensive work was carried out with th Matisa tamping machine, and this absorbed a very high proportion of the mobi gang's time. Afterwards this assumed more ordinary proportions and it is interest that a comparison of time spent on on-track work, combining the efforts the mobile and the length gangs, shows a reduced percentage as compared with th original static length-gang organization. It is considered that the standard maintenance has not fallen, so it would appear that the time has been spent mo effectively. This is to be expected, as there is closer supervision by the mobi ganger and the inspector.

Off track work has, by comparison, gone up, and although there have been sligh increases in travelling time owing to the arrangement for picking up and droppin men at their home stations, the overall picture does indicate that with the larg mobile gangs there is better control.

This closer supervision and planning put much additional work on the Permaner Way Inspector, and to assist him and also to keep a record for comparati purposes, an additional Permanent Way Inspector's Timekeeper was appointe At one time it was thought that an additional sub-inspector might be necessary, enable the Permanent Way Inspector himself to give far more attention directly the organization and work of the gangs, but so far this has not proved necessary.

Large gang trolleys and their operation

It will be appreciated that the men for the mobile gang were drawn from leng gangs throughout the section and during the experimental period their home statio could not be changed. Trolleys were stabled therefore, at Moreton-in-Marsh an Handborough, so as to pick up men throughout the section, the trolley crews havin to book on earlier in the morning and book off later in the evening than th remainder of the gang.

Each trolley, manufactured by Messrs B. Wickham & Co. of Ware, consisted the chassis of their heavy duty officers' inspection type No. 40 Car, with a speci body, powered by a 30-h.p. Ford V8 engine. Seating capacity is sixteen, includin the driver, and the seats, fitted by district staff, are readily removable for transportin plant. The trolleys can be driven from either end and each is fitted with draw-b gear for towing a trailer and a tow-bar for towing out by light engine in the eve of breakdown.

Plant

When the experiment was first started, emphasis was placed on the wo "mechanized" and a certain amount of portable plant was purchased. Such pla included portable generators, pram compressors, Kango hammers, impact wrenche Allen scythes, etc., but in effect, except for the pram compressors, similar items plant had been available for a long time on all sections, and it was not long befo the allocation of plant became part and parcel of the district organization, and was n specially held on the experimental sections. The trolleys, however, are special iten of plant which achieve a high degree of mobility for the gang and in addition ha been equipped for weed spraying.

neral conclusion

As a result of the experience gained throughout the period of this experiment, it as decided that length gangs of 3 or 4 men were too small to be fully effective, but the other hand the advantage of a large mobile gang could not be ignored. It as felt that the static-length-gang strength for each of the 6 gangs should be made to 5 men, the balance of 15 forming a single mobile gang with one trolley based Kingham.

On 2 January, 1956, therefore, the revised maintenance organization came to being on a permanent footing, and it will be noticed that this achieves, in very und figures, a saving of 9 men, or roughly 18%. Such saving will be partly offset the cost of the running of trolleys, and other outgoings, but the net saving should proximate to £2,500 per annum.

The following is a summary of the conclusions which were reached during the formal discussion:—

1. Capital expenditure on improved forms of track and increased ballast would be fully justified in reduced maintenance costs.
2. A length ganger's responsibility should be clear cut, whether it was for all work within the geographical limits of his length or for "on track" work as far as the ballast edge. Mobile gang work should be distinct from length gang work.
3. Some degree of mechanization of maintenance work was justified, both for length gangs and for mobile gangs, but:
   (*a*) mechanical aids should be carefully selected in the light of traffic density on the line concerned; and
   (*b*) efficient maintenance of plant was essential.

Paper No. 6126

A MODERN COAL-LOADING PLANT ON THE RIVER TYNE

by

***George Bruce Marriott, M.Sc.(Eng.), A.M.I.C.E.**

(Ordered by the Council to be published with written discussion)

SYNOPSIS

The Paper describes the design and construction of a berth and mechanical-handling plant at Whitehill Point, North Shields, for loading coal for coastwise and overseas shipment, and for bunkering.

The berth is designed to load at 1,000 tons/hour from two radial loading towers equipped with belt conveyors, fed through short connecting conveyors by two rotary tipplers with an operating cycle of 40 sec and capable of accommodating all wagons of between 10 and $24\frac{1}{2}$ tons capacity.

Special requirements on the strength of the reinforced concrete quay forming part of the berth presented unusual design problems, and the method by which these were solved is described.

Design development of new plant

As a result of the decision in 1951 to close Northumberland Dock, it became necessary to construct a new coal shipping staith with a capacity of at least 750,000 tons/year. The types of coal range from run-of-mine coal to dry and washed filter-cake and slurry. The coal is delivered by any of three existing railway systems, the smallest wagons being of 10-ton capacity with a tare weight of about 6 tons, and the largest of $24\frac{1}{2}$-ton capacity with a tare weight of about 11 tons.

In order to complete the loading of vessels in the shortest possible time it was decided to adopt rotary tipplers, and in order to reduce capital cost to use as far as possible the existing full and empty standage sidings.

The required speed of loading was the first factor to be assessed, and it was calculated that for a normal throughput of 750,000 tons/year, a plant of maximum capacity of 1,000 tons/hour would be required. Although this maximum capacity represents in theory only 750 working hours per year, various delays necessitate the provision of such a high nominal capacity even when the most modern design is adopted, as shown below.

Having settled the principal characteristics of the plant, four possible sites were examined and schemes, with estimates of cost, drawn up, bearing in mind the following:—

(1) Minimum encroachment upon existing loading points.
(2) Maximum use of existing railway systems.
(3) Good berthage facilities to reduce turn-round time of vessels.
(4) Adequate lay-by berthage space.

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* The Author is Senior Assistant Engineer, Tyne Improvement Commission.

Fig. 3.—Tippler house looking north showing control panel room above tipplers

Fig. 4.—Conveyor galleries, shipping towers, and wagon gantry

erth A : normal capacity 750,000 tons/year

	Single-shift working 750,000 tons	Double-shift working 1,100,000 tons
(*a*) Belts running loaded	94 days	69 days
(*b*) Belts running empty owing to delays at, or behind, tippler house	25 ,,	37 ,,
(*c*) Belts stopped owing to trimming, single-belt working, coal not being available, etc.	100 ,,	100 ,,
(*d*) Time lost between full departure and arrival of next vessel	56 ,,	69 ,,
(*e*) Time lost manœuvring vessels during loading	7 ,,	7 ,,
(*f*) Week-ends, holidays, maintenance, and breakdown time	83 ,,	83 ,,
	365 days	365 days

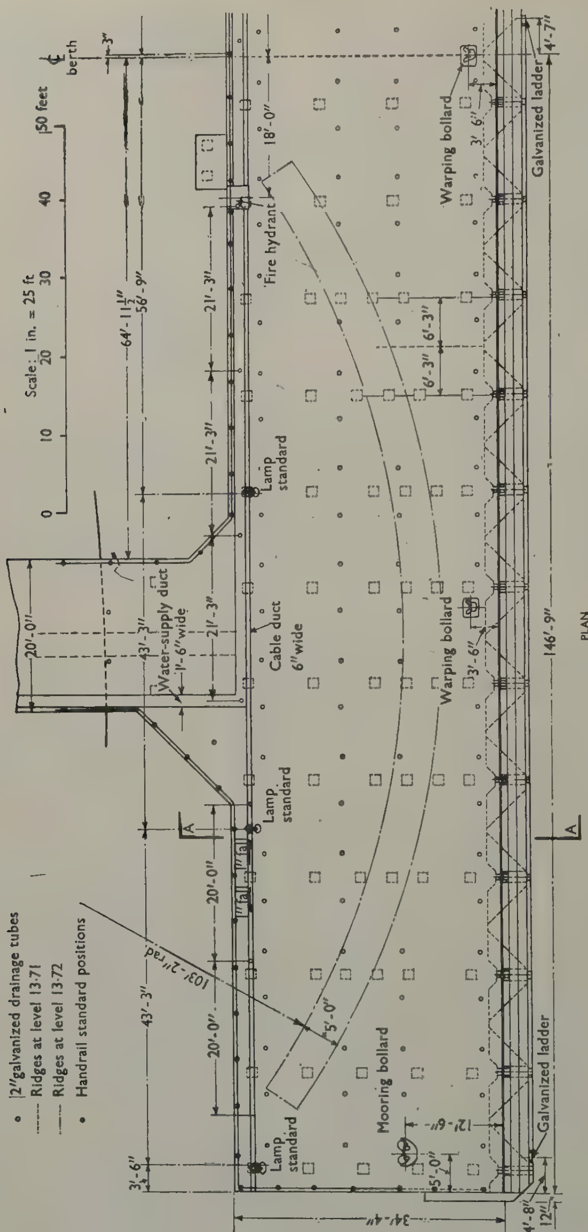
The preliminary investigations were completed by November 1951, and plans were prepared for provision of two berths, each 590 ft long, at Whitehill Point, North Shields. However, in January 1952, as a result of an assessment of future requirements, it was decided to proceed with the construction of one berth only. Use was made of existing timber dolphins and jetty structures at the extremities of the berth and over the central length of 300 ft a reinforced concrete quay was built.

Design of reinforced concrete quay

Boreholes and test piles showed up to 20 ft of river silt and soft clay overlying carboniferous sandstone and shale at 30 to 40 ft below L.W.O.S.T. The hard sandstone and shale had a dip of about 1° riverwards and it was determined by test piles that in many places reinforced concrete or steel piles could not be expected to penetrate more than about 2–5 ft into the hard strata without damage. Consideration was therefore also given to the use of concrete caissons, steel and concrete cylinders, and a cellular sheet-piled quay.

At the same time the use of reinforced concrete piles was investigated further to determine whether a design based upon piles pin-jointed at the feet and encastré within a reinforced deck slab was a possible solution. A scale model was made in mild steel and, by the courtesy of Professor Fisher Cassie, was tested in the Civil Engineering laboratory of King's College, Newcastle-upon-Tyne, to determine the stiffness of the structure under possible berthing loads. The tests indicated that such a design would be quite adequate to deal with the normal maximum design berthing load, namely that produced by a vessel of 10,000 tons displacement striking the quay at a velocity of 1 ft/sec. Such a design would also provide the cheapest form of construction but other considerations made it necessary to connect the jetty structure rigidly to the inner foundations of the mechanical plant, thus forming a monolithic reinforced concrete quay.

It was therefore decided to incorporate reinforced concrete struts carried back to concrete thrust walls built in the ground behind an existing masonry river wall, and to design the quay to withstand the possible impact from a vessel out of control hitting the concrete deck at any point along its face. This impact was estimated for the purpose of design to develop a maximum force of 1,000 tons, the assessment of which is discussed in the Appendix.


2" galvanized drainage tubes
Ridges at level 13·71
Ridges at level 13·72
Handrail standard positions
Scale: 1 in. = 25 ft
0 10 20 30 40 50 feet
℄ berth
Water-supply duct 1'-6" wide
Cable duct 6" wide
Lamp standard
Fire hydrant
Warping bollard
Mooring bollard
Galvanized ladder
103'-2" rad.
146'-9"
34'-4"
PLAN

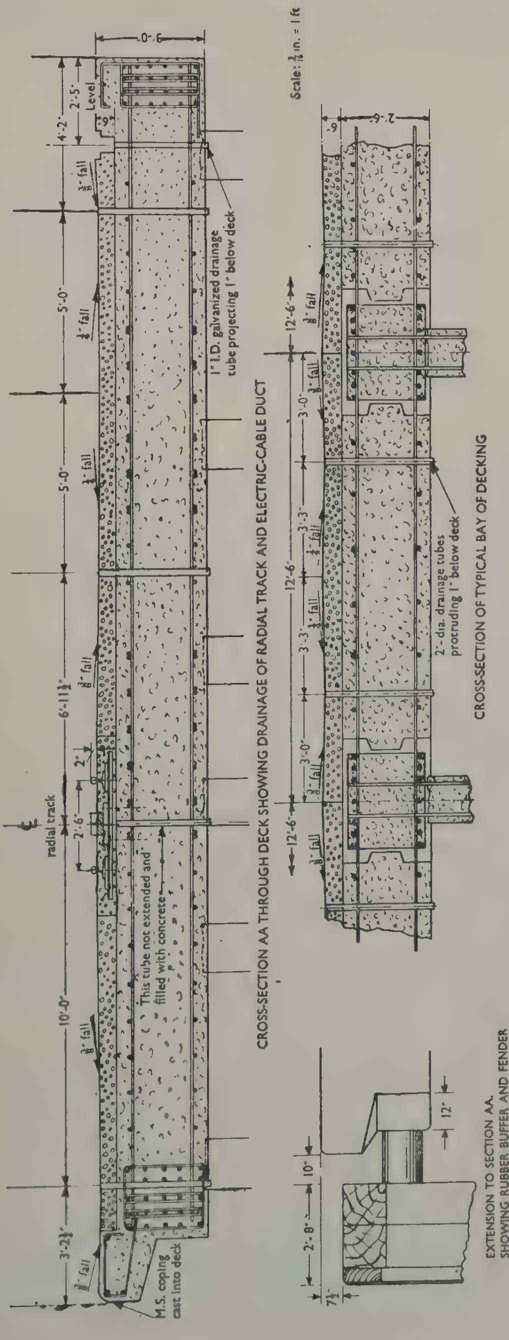


Fig. 1.—Deck Plan and Sections

The deck slab was designed as a horizontal reinforced concrete beam, the reinforcement in the capping beams over the pile bents, disposed at 12-ft-6-in. centres, taking the shear forces. The deck, which is 2 ft 6 in. thick plus $5\frac{1}{2}$ in. of surfacing concrete and only lightly reinforced between capping beams, is designed to carry a 105-ton 4-wheeled bogie of 6-ft wheel-base travelling on a 2-ft-6-in.-gauge radial track, and a normal live deck loading of 6 cwt/sq. ft.

The horizontal struts connecting the jetty structure to the shore foundations consist of two 20-ft-wide by 3-ft-deep slabs having reinforcing gussets of varying depth each designed to transmit a load of 1,000 tons to a reinforced concrete thrust wall 50 ft long by 10 ft deep by 6 ft wide. The thrust walls can transmit a maximum load of 700 tons each to the ground which is assumed to develop its resistance under static pressure.

The quay, which is 294 ft long, provides a single berth 590 ft long with a depth of water alongside of 30 ft at L.W.O.S.T. It is equipped with normal quay facilities including electric lighting and fresh-water points.

Fendering

It was considered that an energy-absorbing fendering system was desirable owing to the liability to damage to the concrete piling by shock loads, and the quay has therefore been protected by a continuous fendering system capable of absorbing a minimum of 40 ft-tons of the energy of a blow delivered at or near deck level. The fendering system incorporates a horizontal continuous timber beam of Douglas fir in front of rubber buffers, as shown in Fig. 1, and when a blow is delivered at or between the positions of the buffers, flexure of the beams will transmit energy to neighbouring buffers. Douglas fir, which has a mean modulus of elasticity of 1,600,000 lb/sq. in., was used for the heavy 14-in by 28-in. deep waling, since no other suitable timber was available. It is common practice in designing fendering to assume that a certain length of facing becomes affected by the glancing blow of a vessel, but when the physical characteristics of the fendering system are known, the length doing useful work under a head-on blow and the amount of this work can be calculated. When considering the effect of a glancing blow, the length of the fendering doing work is dependent upon the shape of the vessel's hull, the angle of the vessel's approach to the jetty, and the flexibility of the fendering system.

Rubber in compression is particularly useful for absorbing the energy of vessels when berthing as the load/strain curve is concave in the higher range of deformation. Compression-test data of one of the buffers specially designed for the new berth is shown in Fig. 2. These buffers, placed at each bent position and faced by a horizontal 28-in. × 14-in. timber spreader-beam carried upon twin fender piles at 12-ft.-6-in. centres provide a fendering system which will withstand:—

(1) A broadside blow from a 10,000-ton vessel approaching at a speed of $1\frac{1}{2}$ ft/sec.
(2) A direct stem-on blow at any buffer position from a 10,000-ton vessel approaching at $\frac{1}{2}$ ft/sec.
(3) A glancing blow on any part of the system at or near deck level from a 10,000-ton vessel travelling at about 1 ft/sec.

The fendering is tied to the quay by adjustable chains disposed at 45° to the face-line and arranged so that the fendering is restrained from movement along the quay face. The chain system is designed to withstand the effect of the glancing blows of ships and is adjusted to give about $\frac{1}{2}$ in. of initial compression to each rubber buffer.

The fender piles have rock shoes and were made in composite form with hewn

reenheart below L.W.O.S.T. and incised creosoted Douglas fir above low water, he joint being made by mild-steel fish-plates and bolts. This proved reasonably conomical and gives protection against the attack of marine borers, particularly mnoria, where it is most needed, i.e., between mud level and about 20 ft above mud evel in this area of the River Tyne.

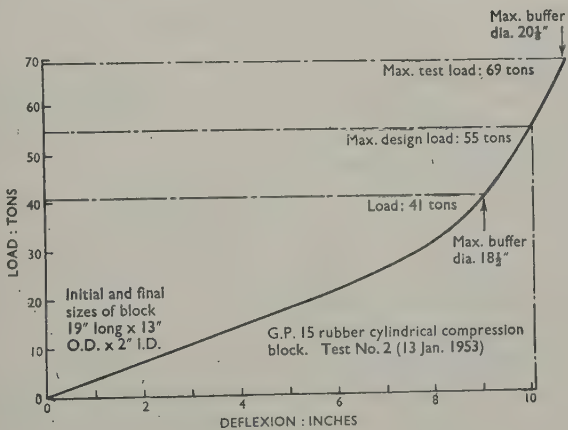


FIG. 2

CIVIL-ENGINEERING CONSTRUCTION

The concrete piles, which were cast on site in timber moulds laid upon a prepared concrete bed, are 16 in. square of 1 : $1\frac{1}{2}$: 3 vibrated concrete and range from 50 to 60 ft in length. They are shod with short-spiked rock shoes, or diamond-pointed shoes, as necessary, and were designed for two-point lifting. Only one lifting hole 15 in. from the head, was used and $1\frac{1}{2}$-in. chamfers were provided at the pile corners. The piles were handled ashore by two 10-ton derricks and were driven from a floating craft. The proximity of a timber dolphin at the west end, a jetty at the east end, and the masonry river wall behind the site of the new jetty, made it impossible to drive the piles in a straightforward manner. Some pile positions which were not accessible to the floating craft were spanned by falsework leaders and the piling hammer was handled by a 10-ton derrick. The use of a floating craft for driving piles is inherently less accurate than other methods but was quite acceptable in this case since the design would allow considerable tolerance in the pile positions. The piles were driven in bents at 12-ft-6-in. centres to a set of about $\frac{1}{8}$ in. per blow of a $3\frac{1}{2}$-ton single-acting steam hammer falling through 2 ft 9 in., and in general at least 5 ft of penetration into shale and sandstone was obtained. Although after driving it was necessary to lengthen a number of the piles, good progress was maintained and the completed bents were secured by heavily-reinforced capping beams 3 ft 6 in. in width.

The capping beams were cast in formwork supported from the concrete piling and were then spanned longitudinally by formwork suspended from them, the deck slabs between them being concreted in two lifts. The formwork was suspended by $1\frac{1}{2}$-in.-dia. M.S. rods passed through 2-in.-dia. galvanized M.S. tubes, the suspension rods being secured between double timber transoms, positioned above deck level.

The galvanized tubes were cast in to form permanent drainage holes in the quay deck, and the surfacing concrete, which was laid after completion of the quay construction work, was screeded to provide falls to the drainage holes, as shown in Fig. 1.

Concrete

The following are the characteristics of the mixes which were adopted:—

Piles: quality E

(*a*) Cement/aggregate ratio 1 : 4·6 by weight. (Note: Daily checks were made of water content of the aggregates and periodic checks of the bulking of the fine aggregates)

(*b*) Average water/cement ratio: 0·46

(*c*) Average density: 155 lb/cu. ft

(*d*) Average compressive strength at 28 days (Portland cement): 5,800 lb/sq. in.

(*e*) Coefficient of variation of compressive strength: 11·2%

Reinforced concrete: quality D

(*a*) Cement/aggregate ratio 1: 6·3 by weight

(*b*) Average water/cement ratio: 0·51

(*c*) Average density: 154 lb/cu. ft

(*d*) Average compressive strength at 28 days (Portland cement): 4,300 lb/sq. in.

The concrete was conveyed to the concreting site in ½-cu.-yd-capacity bottom opening skips and compacted by immersion-type vibrators.

Other civil engineering works carried out included reinforced concrete foundations, a reinforced concrete roadway, two mass-concrete retaining walls, permanent-way work, miscellaneous brick and concrete buildings, and the removal of an existing timber jetty.

The concrete quay with the fendering system, struts, thrust walls, and furnishings was constructed in about 9 months at a cost of £4·7 per sq. ft, or £180 per linear ft of quay.

General description of coal shipping plant

Coal wagons are run down by gravity to two approach tracks leading to a tippler house containing two side rotary tipplers (Fig. 3) capable of handling any size of mineral wagon. A receiving hopper beneath each tippler feeds an inclined 42-in.-wide conveyor belt through a jigging chute which embraces the mouth of the hopper and is self-choking when stationary. Each coal stream passes into the upper storey of a pivot house (Fig. 4) where it is fed on to a second curved jigging chute and thence to the inclined belt of the radial shipping tower.

The shipping-tower conveyor belt rises 45 ft on a gradient of 15° 50′ to the hinged portion of the loading boom which can be raised and lowered through a vertical arc of 42°. The hinged portion of the loading boom is retractable, so that its extreme end can be centered over any point up to 60 ft beyond the face of the quay, and its height adjusted to deliver coal at a maximum elevation of 55 ft above quay level. The loading arm terminates in a rotary spout which delivers coal in any direction into the ship's hold. The shipping tower travels radially upon tracks on the concrete quay to give the rotary spout a transverse range of 110 ft. The radial centres of the shipping towers are located in pivot houses 150 ft apart.

The plant has a normal shipping capacity of 1,000 tons/hour of coal.

Storage and empty-wagon sidings

The design takes advantage, so far as possible, of existing siding facilities and allows for the future addition of a second adjacent plant.

The various gradients of the full and empty roads were selected after careful study of the following factors:—

(1) It was necessary to minimize the risk of damage to the plant from wagons which might get out of the control of the bankrider while leading them down from the full storage sidings, but at the same time the approach-track gradients were to be adequate for rakes of wagons to be led down them under gravity. Catch points were installed at the neck of the full standage sidings and on the approach tracks, which were laid to a gradient of 1 : 98 with a sharp curve of 210 ft rad at the end of the gradient, followed by a length of 100 ft of level track. The tipplers were installed at the level governed by this gradient.

(2) It was necessary that the slowest-running wagons having grease axle-boxes should, upon being shunted out of the tippler, travel clear of the spring-loaded points on the empty-wagon gantry. It was also necessary that modern wagons having oil axle-boxes should negotiate the tracks on the gantry safely. The limiting gradients for these two classes of wagon (assumed to be those gradients at which wagons just moving will maintain their velocity) were found to be 1 : 98 and 1 : 300 respectively.

(3) It was naturally desirable that the speed of a modern wagon when leaving the empty-wagon gantry should be as low as possible and an investigation was made of various types of energy-absorbing buffers for use at the end of the "kick-back", or of slowing the wagons after passing through the points by mechanical or pneumatic retarders. It was found to be impracticable to devise an automatic system for all types of wagon, and it was therefore decided to make the rail level at the extreme south end of the gantry higher than at the tipplers. By the incorporation of suitable gradients and horizontal curves in the empty-wagon tracks, a satisfactory compromise solution was reached.

Wagon axle-boxes

The rapid tippling cycle of 40 sec has reduced the problem normally experienced with tipplers of the loss of oil from the older-type wagon axle-boxes when in the tippled position. Arrangements have been made, however, for the manual replenishment of axle-box oil as necessary, and this operation is carried out when the wagons reach the empty sidings.

Design and erection of shipping plant

All the steel structural work was designed to B.S. 499 and Code of Practice 113/1948, with the exception that no structural member exposed to the weather should be less than $\frac{3}{8}$ in. thick. The shipping towers were designed to allow the future addition of 12-ton anti-breaker derricks and Handcock anti-breakers. The site erection work was carried out by a 6-ton mobile crane and electric winches, and the radial shipping-conveyor galleries and towers were assembled at ground level and lifted into position by a 150-ton floating crane. The floating crane was also used to

position the drive units of the shipping conveyors and the luffing and telescoping drive units on the shipping towers.

The telescoping action of the continuous shipping conveyor belts is achieved by a moving shuttle which is normally stowed beneath the fixed upper part of the conveyor. The shuttle can be moved up the shipping gantry carrying with it the shipping boom which is hinged to the fore end of the shuttle. In order to facilitate erection, the shuttle framing was lifted into, and temporarily fixed in its lowest position after the travel wheels, idlers, conveyor drive, shipping boom, and conveyor belt had been successively installed. The shuttle units were finally pulled up to their operating positions by the telescoping winches in the shipping tower.

The telescoping movement is provided by two $\frac{13}{16}$-in.-dia. wire-rope winches driven by a 30-h.p. motor operating through a 25 : 1 worm reduction gear giving a rope speed of 50 ft/min, and a shuttle speed of $12\frac{1}{2}$ ft/min. Eighteen-inch-dia. automatic brakes are provided in case of drive failure. The retracting motion of the shuttle and boom is not positively driven and should the shuttle become obstructed or jam during this motion, the controlling rope will immediately become slack and operate a spring-controlled slack-rope switch.

The boom luffing motion is operated by a second pair of similar winches.

Each shipping tower travels on a 2-ft-6-in.-gauge radial track of 105-ft-8-in. radius upon two 4-wheeled bogies of 6-ft wheel-base positioned at 30-ft centres, and designed to carry a load from the shipping tower of 105 tons each through a rocking saddle bearing centrally on each bogie. The double-flanged wheels are bushed with gun-metal and revolve on 6-in.-dia. shafts disposed radially to the pivot point and secured to the bogie frames. The travel of the tower through a horizontal arc of 35°-48′ is controlled by limit switches. Provision is made for anchoring the towers during storms at their eastern limits of travel.

The tower traversing gear is operated by a 30-h.p. motor driving through a worm-reduction gear and a train of spur and bevel gearing to a fixed radial cast-steel rack. The tower traversing speed is 21 ft/min and the motion is protected by a solenoid-operated brake between the motor and the worm reduction gear, and by a 500-lb thruster storm brake on the first shaft of the gear train.

The pivot point of each shipping tower and gantry is mounted upon a reinforced concrete portal designed to carry a dead-load of 30 tons plus a horizontal shear load from wind of 18 tons. The dead-load of the shipping gantry is taken through two 8-in.-wide machined tapered rollers of 12-in. mean dia. travelling on cast-steel paths disposed at 6-ft-3-in. radius about the pivot point, where the shear load is taken by a vertical 7-in.-dia. M.S. pin.

About 1,000 tons of structural steelwork and 200 tons of machinery are incorporated in the plant. The conveyor galleries, tippler, and pivot houses, are clad with 20-gauge Robertson's Protected Metal corrugated sheeting, having an aluminium-sprayed finish inside. The roof-lights are of corrugated Perspex sheets and generous side lighting is provided by standard industrial sashes, with centre-hung openings where practicable to facilitate cleaning. The conveyor galleries have 2-ft-6-in. clear walkways at either side of the conveyors, are virtually dust-proof, and their close-boarded timber floors have been treated with Tanalith salts to increase fire-resistance besides preserving them against fungoid attack. Twenty-four fire-fighting appliances of foam and carbon-dioxide types are provided at strategic points throughout the plant.

All structural steel was allowed to weather on the site and after scraping and wire brushing given a priming coat of red-lead followed by two coats of an alkyl-based paint, the finishing coat having a gloss finish.

Conveyors

The conveyor belts are 42 in. wide, with six plies of 32-oz duck, and $\frac{3}{16}$-in. and $_6$-in.-thick grade A rubber coverings on the carrying and undersides respectively. he carrying sides run on five pulley-type idler troughing sets at 4-ft centres, and the eturn idlers at 9-ft centres are of the rubber disk type. All idler sets are provided vith ball or roller bearing lubricated by $\frac{1}{8}$-in.-dia. tubes from grease nipples grouped o one side of each troughing set. The idler pulleys are of cast-iron and rubber-agged in positions subject to shock loading. Continuous $\frac{1}{8}$-in.-thick steel decking lates are fitted between the carrying and return idler sets, so that coal spillage is revented from finding its way between belt and driving pulley. The belts are riven by geared tandem pulleys lagged with $\frac{3}{8}$ in. thickness of rubber vulcanized irectly to the metal. Slip on the second driving pulley is reduced by gearing this ulley to revolve at a slightly slower rate than the first driving pulley. The gearbox atios on the inclined and shipping belts are 9·75 : 1 and 9·8 : 1 respectively, so that he latter belt travels at about 402 ft/min and about 2 ft/min faster than the former.

The cast-iron driving drums are 30 in. dia., 45 in. wide, and crowned $\frac{3}{16}$ in. The ension, snub, head, and tail drums are 24 in. dia. and are similarly crowned to orrect belt wander. The shipping conveyor is provided with weighted take-up gear vhich allows for a maximum stretch of 8 ft in the belt length, and the position of the ail drum of the fixed inclined belt can be adjusted over a length of 2 ft by a screw-ype tensioner.

Since it is required to ship a large proportion of washed small coal and coal slurry, special type of spring-loaded scraper has been fitted at two positions on each belt. The scraper blade is of tempered-steel ground to fit the drum profile. These scrapers emove a considerable quantity of mud-like coal slurry and continuous collecting rays are provided along the length of the inclined conveyor galleries. The slurry is ed, over a fixed spillway, to one of two receiving tanks which also receive the crapings from the tail-conveyor drum. The tanks are provided with screens and overflows to a site-drainage system, and provision has been made for the sediment to be pumped back to the belt when the latter is carrying dry coal.

Receiving hoppers

Receiving hoppers of 80 cu. yd capacity are provided beneath both tipplers. The $\frac{3}{8}$-in.-thick M.S. plate sides are lined with $\frac{5}{16}$-in.-thick carbon-steel wearing plates and are inclined at angles of 45°, 40°, and 50° to the horizontal, giving valley angles of 37°–30′ and 32°–43′. Provision has been made for the addition of screening bars o be placed, when required, 6 ft below the top of the hoppers to exclude occasional arge pieces of iron, timber, or coal.

Each hopper outlet is provided with a power-operated sliding gate with push-button control, so that the feed to the belt can be adjusted to suit the various types of coal handled. The position of the sliding gate is recorded by a pulley and lever system at tippler floor level where a large gauge-board showing the gate setting is easily visible to the wagon marshalling operator.

Transfer and terminal chutes

The outlets of the receiving hoppers are shrouded by curved jigging chutes having a throw of 4 in. at 106–120 reciprocating motions per minute, designed to transfer the coal streams to diverging inclined conveyors. Each chute is carried on two radial

beams of sufficient strength to withstand the dynamic loading and to carry the weight of a column of coal equal to the depth of the receiving hopper. The chute is actuated by a locomotive-type eccentric through a flexible laminated connecting-rod to a horizontal bearing fixed to the outer end of the main supporting beam.

The coal stream is transferred from the fixed inclined conveyor to the shipping conveyor directly above the pivot bearing about which the shipping tower travels. The shipping conveyor can move through a horizontal angle of 17°–54″ on either side of its normal position and the problem of providing an even flow of coal on to this conveyor in all positions was satisfactorily solved by a jigging chute of similar throw and speed to that provided beneath the receiving hopper.

At the position of the tandem-drive pulleys, about half way along the shipping conveyor, the coal stream passes from the fixed section of the conveyor through a fixed chute inclined at 36° to the horizontal, to the telescoping portion of the conveyor. From this point the coal, after passing over the hinge point between the conveyor shuttle and the shipping boom, is delivered through a terminal delivery chute capable of swivelling through 360° in the horizontal plane. The chute is carried in a framing which can rotate about the horizontal shaft carrying the conveyor head drum, and level luffing wires are fitted so that whatever the inclination of the shipping boom, the delivery chute remains horizontal.

All transfer and terminal chutes are lined with $\frac{5}{16}$-in.- or $\frac{1}{4}$-in.-thick renewable 38/42-ton high-carbon-steel wearing plates.

Power units and control system

The mechanical plant comprises twenty-five drive units each complete with electrical and mechanical control, and protection gear. Most of the drives are also subject to sequence control to obviate damage to the plant, danger to personnel, and spillage of coal.

The power supply at the plant is 415/240 V 3-phase four-wire 50 cycles from two 750-kVA oil-cooled transformers, one acting as spare. The power is distributed from a main switchhouse erected within the tippler house and from two control-gear houses adjacent to the pivot houses. With the exception of the tower motions, all drives are controlled by push buttons, and rectifiers are supplied for the operating coils of all motor-contactor panels. The jigger and conveyor drives are normally under sequence control from the tower control cabins and are protected by under-speed tripping devices actuated by transmitters from chain-driven tachometers.

Push-button controls are also provided for testing purposes, near the respective motors. The drives are provided with emergency stop buttons, and with emergency trip wires along either side of each conveyor belt. Klaxons have been fitted in all galleries to give audible warning of the impending start of any conveyor and loud-ringing bells are similarly provided near the jigging chutes. A loud-speaking telephone connects the wagon-marshalling control station with the shipping control cabins and with the operator's mess room.

The conveyor lines are controlled from console desks in the shipping-control cabins, the desks being equipped with push-button controls, ammeters, and illuminated mimic strips which indicate when each drive has attained full speed. The jigger drives are provided at the jigger positions with hand-operated variable-speed controls mounted in separate cubicles.

All motions of the shipping tower and boom are controlled by limit switches, the luffing and telescoping screw-type limits being interdependent under the action of a cam plate shaped to provide the required boom clearances in all positions.

The wagon-marshalling and tippling control gear is quite independent of the ontrol cabins on the shipping towers. The marshalling operator has a push-button tation to control the operation of the charger, beetle, and tippler on each side of the lant, the various mechanisms being protected by limit switches, sequence controls, nd positional recorders to ensure that the operation of emptying the wagons takes lace without danger to personnel or to the plant. The sequence can be carried out nder "Hand", "Semi-automatic", or "Automatic" control, and master controls or the tippling motions are provided in an overhead control and cubicle room, so that agons can be re-tippled if frozen coal is not cleared at the first tippling operation. opper-full switches are provided to prevent over-filling of the receiving hoppers, nd three photo-cell units on each track are incorporated in the sequence control ystem.

Ancillary buildings

The following buildings, constructed of brickwork with reinforced concrete roofs, orm part of the plant:—

(1) Sub-station, housing transformers and switchgear.
(2) Electric control panel and transformer houses adjacent to the east and west pivot houses.
(3) Fitters' shop, electricians' shop, mess room, lavatories, drying room, oil store, and coal samplers' testing room, all adjacent to the tippler house.

The tippler and pivot-house walls have been constructed in 9-in. brickwork up to 0 ft above ground level. The tippler house contains the lighting and power switchear rooms.

Acknowledgements

The Author is indebted to Mr R. B. Porter, B.Sc., M.I.C.E., Chief Engineer of the yne Improvement Commission, under whose direction the works were carried out, or permission to present this Paper.

The contract for the civil engineering works was awarded to Brims & Co. Ltd.

The detailed design and erection of the structural, mechanical, and electrical work as carried out by Simon Handling Engineers, Ltd.

Strachan & Henshaw, Ltd were the sub-contractors for the marshalling and ippling equipment.

APPENDIX

INVESTIGATION OF THE EFFECT OF A COLLISION BETWEEN A VESSEL AND THE QUAY

It will be seen from reference to the general arrangement of the quay (Fig. 1) that the aximum stress is developed in the structure if the vessel strikes at its extremity. It is ssumed in this investigation that a vessel of 10,000-ton displacement is the largest that ould be involved in a collision of this nature.

The simplest form of work diagram for a stem-on collision between a perfectly elastic essel and quay is as shown in Fig. 5a, in which the area beneath the curve can be equated o the kinetic energy of the vessel at the instant of impact.

The value of the maximum force developed on the quay can thus be determined if the inetic energy of the vessel is known.

Referring to Fig. 1 and neglecting the restraint given by the vertical piling, it will be een that the ends of the quay can be considered as horizontal beams of length 67 ft cantiovered from the positions of the two roadway struts.

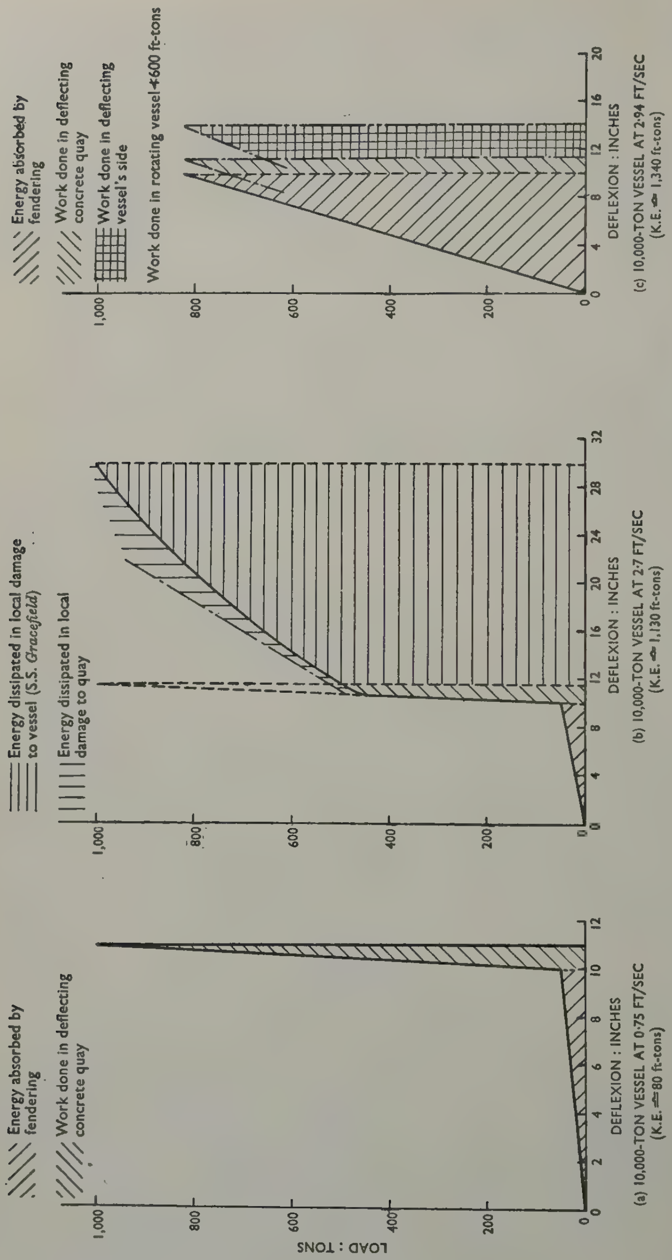


FIG. 5.—APPROXIMATE WORK DIAGRAMS FOR COLLISION BETWEEN VESSEL AND QUAY

The strain energy of one such cantilever:

$$S = \int_0^{67} \frac{wx^2dx}{2EI}$$

d where $w =$, say, 1,000 tons, $S = 34{\cdot}1$ tons-ft.

Similarly, the maximum strain energy of one roadway strut and thrust wall is about tons-ft.

If the total amount of energy absorbed by the quay and fendering be assumed to lance the kinetic energy of the vessel, it is found that the vessel's velocity is limited to out $\frac{3}{4}$ ft/sec.

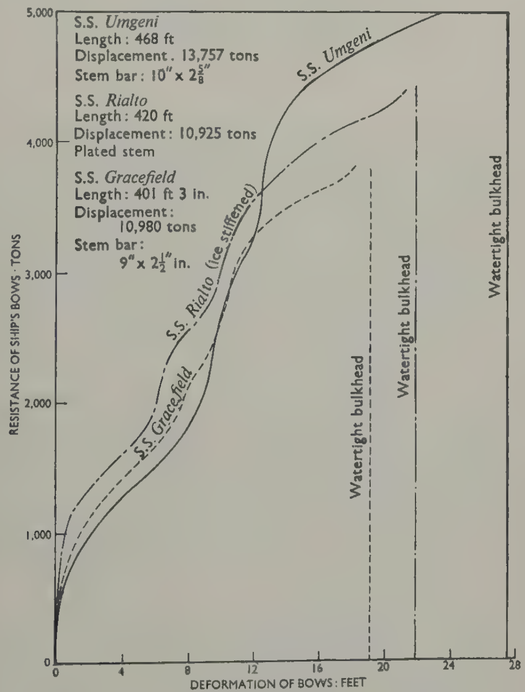


FIG. 6.—APPROXIMATE IMPACT STRENGTHS OF TYPICAL VESSELS

However, it has been demonstrated (Fig. 6) that before an interacting force of 1,000 ns has been reached, energy will be dissipated in local damage to the ship. An in-terminate amount of energy will also be dissipated in local damage to the quay and in sruption of the fendering. The work diagram is therefore of the shape indicated in g. 5b. If the indeterminate energy involved in impact losses and in disruption of the ndering is entirely neglected, the energy absorbed (given by the area under the full line, g. 5b) amounts to 1,200 ton-ft. Equating this energy to the vessel's kinetic energy, it found that the vessel's velocity is 2·7 ft/sec, or about 2 knots.

Consideration of the more normal case where the vessel strikes the quay obliquely, ows that energy will also be dissipated in swinging the vessel about its own mass centre.

Where the approach angle is small, the maximum instantaneous load P imparted to the quay by the glancing blow of a vessel, is given by:

$$P^2 = \frac{V^2W}{g \cdot d}(1 + c^2/k^2)$$

where V, W, denote velocity and weight of the vessel
C ,, distance of the centre of mass of the vessel from the point of contact with the quay, measured parallel to the quay
k ,, radius of gyration about a vertical axis through the vessel's mass centre
d ,, compression produced on the fendering system by unit load

In the derivation of this formula it is assumed that the vessel remains rigid, that the blow occurs in a horizontal plane which contains the centre of mass of the vessel, and that the effect of the momentum of the water moving with the vessel can be neglected.

An average value of c^2/k^2 for typical colliers of 10,000-ton displacement is 2·9, and since the ship is considered to strike the quay a glancing blow, a number of rubber buffers, N, will be compressed. This number governs the resilience factor d of the above formula, and for a speed of, say, 2 knots, $N = 15$ and the instantaneous load P on the quay = 825 tons.

Where fifteen buffers operate, a length of about 175 ft of the fendering would be in contact with the vessel.

In such a case energy would also be absorbed in the elastic deformation of the ship's side and of the concrete quay, and the work diagram is approximately as shown in Fig. 5c.

A collision in which the angle of approach is large would result in increased local damage to the fendering and in some local damage to the vessel. The work diagram would thus incorporate factors from both diagrams Figs 5b and 5c.

An inspection of the work diagrams (Figs 5b and 5c) indicates that an interacting force between quay and vessel of 1,000 tons can be accepted as a reasonable maximum for the design of a quay, having regard to the particular local conditions, and that if so designed the quay could withstand, without damage to the mechanical plant, a collision from a normally-constructed vessel of 10,000-ton displacement travelling at about 2 knots.

The Paper, which was received on 20 June, 1956, is accompanied by four photographs and five sheets of diagrams, from some of which the half-tone page plates, and the Figures in the text have been prepared.

Correspondence on this Paper should be forwarded to reach the Institution before 15 January, 1957. Contributions should not exceed 1,200 words.—Sec.

CORRESPONDENCE

on Papers published in Proceedings, Part II, June 1956

Road Paper No. 49

"The planning of ring roads, with special reference to London" †

by

Frank Alan Rayfield, M.I.C.E.

Correspondence

Mr **L. W. Lane** (Senior Planning Officer, London County Council) observed that hough post-war proposals for an inner London ring road, which had originated in e County of London Plan 1943, had been subsequently discarded, radical thinking on e London traffic problem had never been more necessary than it was today.

The Author presented a closely reasoned set of arguments for the innermost ring road be of a motorway character, whereas the County of London Plan proposed a road of b-arterial character in that position.

The Author's major argument derived from the factor of speed. In so doing, he under-timated the importance of the other factors affecting location—particularly ease of cess and egress, and amenity for drivers. With regard to the former, the limited mber of access points proposed, the possible difficulty of getting to them, and waiting ne at those points to get on and off the road might well counterbalance the speed when tually on the motorway. In respect of the latter point, the criterion of many drivers s measured not so much in actual minutes and seconds as in comfort and apparent eed, which would appear greater if continuous movement was maintained. If that was it might be that a well-designed surface sub-arterial scheme might do the job equally ll at considerably less cost.

Whatever the validity of those points, the major planning issue to be considered was effect of an "A" ring motorway upon the existing character of inner London.

Just as in the countryside, it would be reasonable to expect a motorway to adapt itself hill and valley, so in the urban scene a new road would be expected to adapt itself to at might be called the "social contours" of the town. Thus, an inner ring road could expected to mark the limits of the central area or to pass between areas of different ial and use characteristics.

That the inner ring-road motorway failed to do. It would cause serious disturbance the established structure of central London, cut up well-defined residential com-nities, and disturb precinct boundaries. The road would, in fact, pass through the art of Pimlico, Belgravia, the Portman Square area, the Harley Street area, the ndon University area and Bloomsbury. About a dozen London squares would be stically affected. In order to assess some of the effects of the road upon the areas rough which it would pass, it was only necessary to consider Fig. 11 in terms of, say, the rley Street area or Belgravia. Numerous ugly flank walls would be exposed and the ultant sites on either side would often be difficult and unattractive to redevelop.

† Proc. Instn Civ. Engrs, Part II, vol. 5, p. 99 (June 1956).

In addition to the physical disturbance, considerable social disruption would ensue.

Finally, the displacement of population caused would amount to about 20,000 persons. In other words, it would be necessary to build a complete small new town to accommodate the overspill from that project. Although in central London road improvement must inevitably cause serious disturbance to property, it was to be questioned whether the disturbance caused by an "A" ring motorway was not too heavy a price to pay for the benefits gained.

Mr J. I. Whitehead (Assistant County Surveyor, Dorset County Council) said the Author seemed to assume that a road forming a closed circuit was intrinsically a sound proposition, and, in the absence of justification for that in the Paper, the general trend of Mr Whitehead's remarks was directed against it.

It seemed a pity that the Author had not emphasized in Part I of the Paper the need for traffic studies, whereas in Parts II and III he dealt with those in some detail. In the absence of traffic surveys, the concept of a ring road for a small town with less than about 100,000 inhabitants appeared to be derived from the planner's liking for neat geometric figures in the arrangement of road proposals. Mr Whitehead had illustrated in a previous Paper[15] the principle of overlapping by-passes which the Author had mentioned under the heading of "Basic Principles", but he had found no justification for complete ring roads. Moreover, in the largest town studied therein (Reading, population approximately 100,000) no demand had been found for inter-suburban traffic facilities such as a ring road would give. The Author had produced no case for the extension of the overlapping by-passes to form a complete ring road, and the reader was left in doubt as to the merits of the ring-road principle.

Some resolution of the differences (see p. 100) between "Official views" and "Current proposals" would also be expected. In the former, the outer ring road was stated to be needed primarily for *local* traffic. In the latter, the absence of ring roads in new towns was said to arise from the possibility of providing for *through* traffic in other ways. Again there was uncertainty about the Author's opinion on the justification for ring roads, and the type of traffic he believed they would accommodate.

Much of Part III was not peculiar to ring roads, and it was difficult to detect at what stage the Author became convinced that the complete ring was essential. It might be that the diversity and numbers of possible journeys in London defied analysis, and the Author, starting with the conviction that any new road would take traffic from less attractive routes, and being unable to detect any one strong journey trend, was driven to the ring-road shape as the best compromise for the new road. In the unique circumstances of London traffic, he was probably right because there would always be enough traffic in London willing to use all parts of a ring road, but a distinction should be made in name between the by-pass type of ring road for a small town and the internal relief type suggested for London in Part III. They seemed to be quite different in principle.

Mr Joseph Rawlinson (Chief Engineer, London County Council) remarked that it would be difficult to exaggerate the importance of finding a satisfactory solution to the traffic problem in the central area of London. The Paper described the problem and a suggested solution in the form of a ring road located as near as practicable to a position which would offer the best relief to traffic generally in that area. The cost of £130,000,000 was formidable and an annual charge of about £5,200,000 excluding maintenance, might well prove to be too heavy a financial burden for any one Local Authority.

But something had to be done, and done quickly, if serious dislocation in the traffic system was to be avoided. Some authorities were of the opinion that the time had arrived when immediate steps should be taken to "push through" at all costs one or more of the many major improvement schemes which had been put forward from time to time by the London County Council.

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[15] J. I. Whitehead, "Directional Traffic Surveys". Road Paper No. 30, Instn Civ. Engrs, 1950. See Fig. 9.

Was there any alternative at a similar cost to the ring road described in the Paper which ould offer anything like the same relief to the over-congested central area?

In 1946, immediately after the cessation of hostilities many small areas of land in the ntral area of London had been vacant as the result of enemy action. It would have en possible in those days to take advantage of some of those sites in locating road provements, including the "A" ring road. Alas, owing to financial restrictions on pital expenditure imposed by successive governments, urgent road improvements had en postponed with the result that today most of those sites were now built-up and the ssibility of acquiring them for new road works was very remote indeed.

The Author had described the position of the proposed ring road, and it would be adily appreciated that certain sections of the work would offer greater obstacles than hers. One very difficult section would be the portion lying between Bayswater Road d Tottenham Court Road, another the section which would pass through Belgravia.

The length of the ring road on the south side could still be constructed with little more sturbance than would have been necessary immediately after the war, and if and when mpleted would make a very great contribution indeed to the relief of traffic congestion the south side of the river.

The construction of the "A" ring, or that portion of it which lay on the south side of the er was now a matter for the Government but it had been turned down once on the ound of expense, and since that time the estimated cost for the whole scheme had risen om £80,000,000 to £130,000,000.

The traffic in London was increasing from year to year, adding much additional expense all forms of road transport, which the country could ill afford to meet.

If it was now impracticable to construct the whole of the "A" ring—and that was not mitted—then steps should be taken at once to implement, at any rate, some portion of ring-road scheme.

The Author, in reply, observed that Mr Lane's comments were of two kinds, *viz*, affic and the effects of a motorway ring on the character of inner London. The Author d drawn attention to the necessity for careful siting of the outer points and for adequate pacity of the approaches, and the time factor had been taken into account. The ajority of drivers in inner London during the working day were regular drivers engaged r the most part on business of one kind or another. With them time meant money and ring road would be attractive. From the points of view of amenity and comfort the thor considered that the ring road would be far more attractive and less tiring than rface roads. He agreed that a well-designed surface set of improvements might achieve same object but, as he hoped he had demonstrated, the cost would not be considerably s but more than double.

He was not able to appreciate why the ring road should necessarily define areas of fferent social and use characteristics. A normal main road usually had similar develop- ent on both sides, in spite of the physical difficulty experienced by pedestrians in crossing With the ring road, above or below ground level, pedestrian crossing movements uld be much easier and safer and all important vehicular crossings could be preserved. e problem of treating exposed party walls arose in most street widenings and improve- ents and, in his experience, was not an intractable one. Not a square yard of open space uld be lost and he felt that the adverse effect, even if it existed, upon central London enities was greatly exaggerated and considered that there would be no social disruption all. The re-housing problem was common to most street improvements and would have be faced whatever was done.

Mr Whitehead did not agree that the case for a ring road had been established, but the thor, in Part I of the Paper had merely attempted to outline the basic principles of the ception and not to examine the practicability or desirability of a ring road in the e of small or moderately sized towns. Each would have to be considered on the facts the case (towards establishing which traffic studies were obviously of prime importance) t he felt that it would usually be found that a ring road of the motorway type would be ficult to justify economically. The possibility of different solutions in different towns

made it impossible to reconcile in general terms official views and current proposals. Theory and practice did not always go hand-in-hand.

Part III of the Paper dealt with the case for a simple ring road project for London. Such a project might or might not be the best or least expensive method of achieving a certain traffic object (although the Author thought that it would be in the present case) and the Paper showed how that project was assessed. The method could be applied to ring roads in other towns, where the Author agreed that in smaller centres of population the results might well be found to be adverse to a motorway type of ring, or to other types of proposals.

Mr Rawlinson had stressed the importance of finding a satisfactory solution to the traffic problem in inner London and the high cost of one of the possible solutions. But the cost to the community of traffic delays was also extremely high and heavy expenditure would be economically justifiable. Because of building development since the war it was unfortunately true that the original alignment proposed for the "A" ring road would probably have to be considerably modified if the project were resurrected. He agreed that south of the Thames such modifications would probably be much less extensive and property acquisition would be less expensive per unit of length than north of the river. The construction of that part of the "A" ring road south of the river would provide valuable additional traffic facilities, particularly if it could be taken across the river, either to Gardiner's Corner in one direction or to Eaton Square in the other.

Maritime Paper No. 31

" Reconstruction of the Gallions Lower Entrance Lock at the Royal Docks of the Port of London Authority " †

by

John Alfred Fisher, M.I.C.E.

Correspondence

Mr J. A. Williams (a Senior Civil Engineer, Sir William Halcrow and Partners, Consulting Engineers, London) observed that he had been concerned during the past few years with works almost identical with those described. He made the following comments on particular aspects of the Paper.

Strengthening of dock walls.—The problem in which Mr Williams had been concerned was to widen and deepen a dry dock, and a design embodying heavily reinforced concrete L-shaped underpinning was evolved—very similar to the knees used at Gallions Lock. Unfortunately the project had not got beyond the tender stage, but although a fairly detailed construction scheme had been prepared there had remained a doubt concerning the best method of cutting blocks of existing concrete. Did the Author have any reservations to make concerning the Siskol mining cutter which he had used and would it be possible to give any indication of its operating costs and output?

Lock gates.—As a general rule civil engineers did not prepare detailed designs for valves, pumps, and similar machinery; tenders were received from specialist manufacturers who supplied either standard equipment or their own special designs. Lock gates seemed to

† Proc. Instn Civ. Engrs, Part II, vol. 5, p. 136 (June 1956).

a "half-way house" where some engineers prepared fully detailed designs and drawings hemselves whilst others did not. In several recent cases with which Mr Williams had een concerned a very full specification for the gates had been prepared together, of course, ith detailed drawings of the recesses, housings, and other purely "civil" work and competitive tenders for the gates themselves had then been invited on those documents, the nderers submitting designs and drawings for scrutiny with their tenders. Much could e said for and against that system and Mr Williams asked the Author what procedure e had adopted and, if, from experience gained at Gallions Lock, he would suggest nything different for future works.

Old brickwork.—Mr Williams's experience coincided exactly with that described in the aper. It was a most depressing business to open out a seemingly small area of defective rickwork in an old lock wall and to find extensive cavitation behind, knowing all the hile that the same would no doubt be found throughout the whole lock. In the case f the work on which he had been engaged the condition of the brickwork justified reinstatement, but that had to be carried out between tides and lockings. Consequently ork was intermittent and it tended to drag on for a long time; when completed it seemed s though little had been achieved for a lot of money.

Flexible fenders.—There was a slight reference to those at the end of the Paper. Presumably they were now built and it was therefore too late to proffer any comments from ast experience which would be of any material assistance to the Author. If a sketch of he design, with a note of any operational experience, could be given by the Author, it ould be much appreciated. From the brief description given it was assumed that the iles of the fender were vertical and in a single line, surmounted by the reinforced concrete beam, the energy of impact on the beam being absorbed by pile bending. Similar fenders designed by Mr Williams's firm were believed to be the first of that kind ever built and the "pioneer" calculations had not been easy. Precise mathematical design was impracticable since, strictly, each pile presented a different "unknown", requiring an additional strain-energy equation. However, a judicious balance of mathematics, model results, and, latterly, full-scale tests had enabled a sound working basis of design to be formulated, but any further observations on prototypes would clearly be very useful. Early construction had also posed some problems which it was hoped would be avoided in future designs. An account of the Author's approach to the problems of design and construction would be of great interest.

Mr F. M. Easton (Assistant, Steelwork Design, British Railways, Western Region) said the design of the lock gates (Fig. 10, Plate 2) showed the special advantage of all-welded construction in that class of work; the saving of weight enabled the buoyancy chambers to be made so small in depth that the middle and outer gates could be operated at low tidal levels without heavy wear on the greenheart heel-posts. But, for the inner pair of gates, would it not have been better to place the drainage scuppers of the ballast chambers on the flat skin rather than on the curved, so that at low tide the chambers would be free of ballast water and accessible for cleaning and maintenance? Otherwise, the accumulation of mud on the constantly immersed ribs might be troublesome. In several pairs of gates at the South Wales ports, the scuppers had been designed to come on the flat skin, or had been transferred there from the back of the gates, without any risk of uplift under differential heads of water on the front and back. The friction between the heel-posts and hollow quoins could be safely relied upon to prevent trouble; a coefficient of friction as low as 0·15, or even lower, was sufficient.

The adoption of phosphor-bronze for the material of the pad inside the heel socket (Fig. 5, Plate 1) was an interesting departure from the more usual material, forged steel, and should result in a considerable reduction in wear on the pintle.

For what reason had the quoin stones (Fig. 3, Plate 1) been dressed back? If a flat bearing surface, tangential to the face of the clapping sill, could be provided, together with a similar flat on the heel-posts, the wear on the timber would be retarded.

The design of the gate operating machinery was an interesting innovation, and, in

performance, the machinery was likely to be free from the troublesome features characteristic of the types more usual in Britain. The spring-loaded buffer at the crosshead was noteworthy. Had it facilitated the "jockeying" of the gates when mitring together in rough water? If details of measured performance could be given, including the total thrust on the racks, the speed of the gate (maximum angular velocity and time of complete opening or closing), the depth of water on sill at the time of the observations, and the effect of wave action on the performance, the information would provide valuable data for the design of gate machinery of all types.

The Author, in reply to Mr Williams's question on the Siskol mining cutter, said it had been found unnecessary to make any reservations as to its particular use, but in practice it was found to be more effective on single cuts. It had been tried on parallel cuts 2 ft 9 in. apart to form a trench, and had not proved so effective. The output of the cutter working on a continuous line to a depth of 7 ft could be taken as between 1 and 2 sq. yd per 8-hour day. A limiting factor was the hardness of the material which necessitated frequent attention to the bit. On hard cutting it was found necessary to re-grind the bit after $1\frac{1}{2}$ sq. yd of cutting.

The lock gates at Gallions had been fully designed but minor modifications in detail to suit the contractor's equipment had been approved. The Author believed that the advantage to be gained with a full design was that plate thicknesses, etc., were specified in detail and that gave more uniform tendering in consequence.

Work on the flexible fenders was still in progress and it was not yet possible to give any opinion. The design was for a concrete cap 8 ft wide $\times$ 10 ft deep $\times$ 137 ft long, supported on 22 in. $\times$ 12 in. broad-flanged beams spaced at between 3-ft and 4-ft centres, driven at a rake of 1 in 5, and having a penetration into chalk of approximately 20 ft.

In reply to Mr Easton, the sluice stones had been dressed back because of initial wear. The original contract had anticipated dealing with that work in situ. The stones had been found to be loose at the joints and had been removed. The use of a flat tangential face would have necessitated an eccentric pivot, and that could not be accommodated within the gate recesses already existing.

Tests had been carried out on the machinery and average values of the results were given in Table 2.

TABLE 2

	Motor b.h.p.	Amps	Volts	Dock level	River level	Operating time	
						Raise	Lower
Sluices	20	$\frac{13}{18}$	415	38 ft 0 in. Newlyn datum	16 ft 0 in. Newlyn datum	2 min 13 sec	2 min 38 sec
						Close	Open
Gates	26	$\frac{19}{28}$	415	—	—	1 min 38 sec	1 min 37 sec

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